

# **THE ANIMAS WATERSHED PLAN**

**Updated May 2013**

## **Plans for Remediation of Historical Mining Sites**

### **In the Upper Animas River Basin**

Animas River Stakeholders Group  
Office of the Coordinator  
8185 C. R. 203  
Durango, CO. 81301

Phone and Fax (970) 385-4138; email: [wsimon@frontier.net](mailto:wsimon@frontier.net)

Phone: (970) 259-0986; email: [butlerpeter2@gmail.com](mailto:butlerpeter2@gmail.com)

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## I. INTRODUCTION

The Animas River Stakeholders Group (ARSG) is a collaborative effort involving a wide range of public and private interests including the Colorado Water Quality Control Division (WQCD) and the EPA, Region VIII. The group is committed to an interactive, open forum where all interested parties are involved in the design and implementation of watershed improvements. The mission of this group is to improve water quality and aquatic habitat throughout the Animas River Watershed. The primary focus of attention is directed to reducing water quality and habitat impacts created by historical mining practices in the Upper Animas basin, near or above Silverton, Colorado. Activities include monitoring and analyzing water quality data, assessing the impact of contaminants and channel modifications on aquatic life, evaluating the feasibility of cleanup actions and formulating, implementing, and assisting with remediation activities.

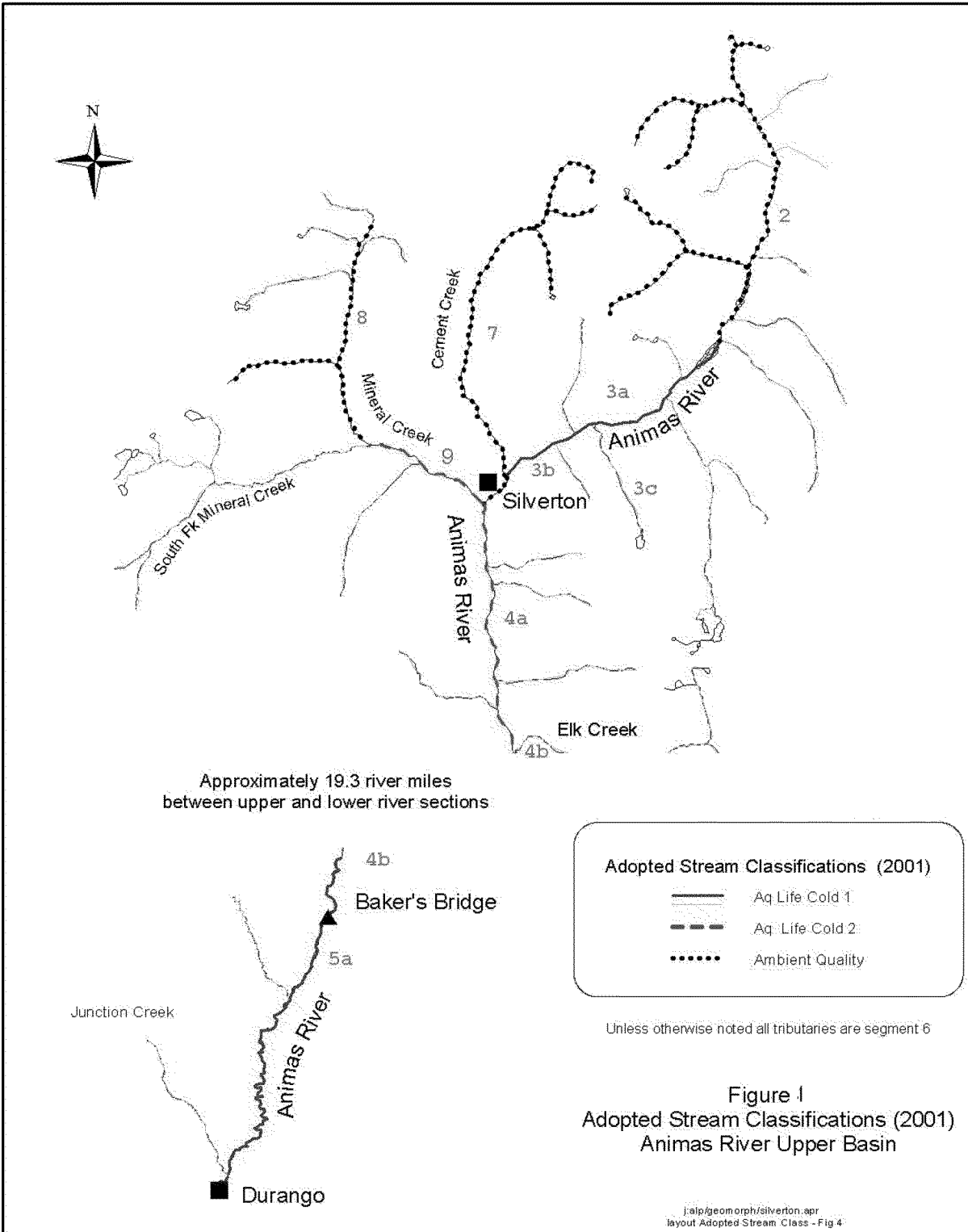
ARSG has no direct authority; however it developed an extensive Use Attainability Analysis (UAA) used to recommend the establishment of appropriate stream use classifications and standards that are based upon partial remediation of major anthropogenic sources of metals pollution. The UAA also sets remediation objectives that will lead to attainment of those classifications and standards within a 20 year period. In addition, the group provides monitoring, characterization, and remediation technical expertise to appropriate land managers, regulatory and enforcement agencies, and private landowners.

ARSG has an established record of obtaining funds and implementing programs that establish environmental stewardship while improving water quality and aquatic habitat. Through education programs and participation in this collaborative stakeholder process, it is anticipated that renewed community stewardship will achieve cost-effective and long-term protection of our water resources.

This Animas Watershed Plan is based upon the Animas UAA (Simon *et. al.*, 2001). Recommendations in the UAA for use classifications and numeric water quality standards throughout the upper Animas River Basin were adopted by the Colorado Water Quality Control Commission (WQCC) and approved by EPA in 2001. Figure 1 shows a map of the upper Animas River Basin, the different stream segments and aquatic use classifications. The adoption was based upon detailed information provided in the UAA as to sources to remediate, associated costs, expected reductions, and the biological potentials of the receiving streams. A Table of Contents of the UAA is provided in Appendix A. A CDROM copy of the complete document (exceeding 1000 pages, not including the database) is available by contacting Bill Simon at (970) 385-4138 or email: [wsimon@frontier.net](mailto:wsimon@frontier.net).

In 2002 the WQCD adopted 29 Total Maximum Daily Load limits for streams throughout the Upper Animas watershed above Baker's Bridge, which is located 12 miles north of Durango (Figure 2). The TMDL's were developed from the existing conditions and newly adopted standard calculations provided in the Animas UAA, Chapters X and XI.

**FIGURE 1- Map of Upper Animas River Basin**



## **Changes Since 2004**

Since development of this watershed plan in 2004, different remediation projects have resulted in changes in water quality. Water quality has improved in some areas and declined in others. This 2013 watershed plan updates the 2004 plan.

The biggest changes have occurred in upper Cement Creek in the vicinity of the old town site of Gladstone. In the early 1990's, the American Tunnel, located at Gladstone, provided access to the Sunnyside mine workings, by far the largest hardrock mine in the Animas River Basin. In 1991, the mine was shut down and reclamation began. As part of its reclamation plan, and under a consent decree with WQCD, Sunnyside Gold Corporation installed multiple bulkheads in the American Tunnel and in numerous other locations throughout the mine workings. Over several years, the bulkheads backed up groundwater creating a mine pool in the workings at least 1,000 feet deep. With minimal drainage through the American Tunnel, the groundwater table rose and groundwater began to surface in new locations. While drainage from the American Tunnel dropped from 1,600 gallons per minute (gpm) to about 100 gpm, drainage from other mines in the area greatly increased, starting around 2003. Overall, mine drainage to Cement Creek changed from having 1,600 gpm of *treated* discharge to having 600 – 800 gpm of untreated discharge. The increase in metal loading due to the additional untreated discharge can be seen at least 40 miles downstream in the Animas River. Because ARSG's focus has been upon the characterization and feasibility to remediate abandoned mines, it did not anticipate or much less evaluate the consequences of the consent decree.

## **II. PROBLEM DESCRIPTION: CAUSE AND SOURCE IDENTIFICATION**

This Plan has been specifically written for the Animas River and its tributaries above Baker's Bridge. Major tributaries to this upper portion of the Animas include Cascade, Needle, Elk, Mineral, and Cement Creeks. Below Baker's Bridge the Animas River flows to its confluence with the San Juan River in northern New Mexico.

The existing physical, chemical, and biological conditions related to water quality have been monitored for several years, analyzed by the ARSG, and condensed into the Animas Use Attainability Analysis (Simon *et al.*, 2001). The following paragraphs have been slightly modified from Chapter III, pages 2-5 of that document.

### **Watershed Characterization**

*Much of the work done by ARSG and done under the AML program has been characterizing the watershed. This includes identifying and understanding the sources of metal loading and how those loads are transported down the watershed, identifying factors that may limit aquatic life such as metal loading and habitat, and analyzing sediment data for metal concentrations pre- and post-mining. The following paragraphs briefly summarize some of the data that have been collected. Later chapters describe the results of analyses of the data. Many of the actual studies are included in the Appendices.*

*The sheer size of the Upper Animas Basin and multitude of loading sources, whose contributions change with the seasons, has made watershed characterization a monumental task. The Basin includes three major drainages: Mineral Creek, Cement Creek, and the Animas River. It covers 146 square miles - 93,000 acres (Leib, 2000) and has over 1,500 patented mine sites. U.S. BLM has inventoried another 300 unpatented sites on its lands. (Hite, 1995) In addition, the Colorado Geological Survey inventoried sites on U.S. Forest Service land in the La Plata and Animas River drainages and found over 800 sites. The majority of these were in the Upper Animas Basin. (Lovekin *et al.*, 1997) While all of these sites contribute*

*substantial metal loads, a large amount of loading comes from non-identifiable sources.*

## ***Water Quality Data***

*Some of the first investigations into water quality on the Animas River occurred in the 1960's. More water quality work and a couple of biological studies were completed in the 1970's. These reports are summarized in a report by Allen Medine (Medine, 1990). A use attainability analysis was conducted on the Upper Animas River and Cement Creek in 1984 by Western Aquatics for the Standard Metals Corp., owner at the time of the Sunnyside workings (Western Aquatics, 1985). All of these studies identified heavy metal loading as the main inhibiting factor to aquatic life.*

*It is difficult to compare much of chemical and biological data from these earlier investigations to studies conducted in the 1990's because the parameters measured and field and analytic techniques used were frequently different than those measured and used today. However, it does appear that there have been definite improvements in water quality and biologic health of the Animas River. Some of the same chemical parameters have improved and more fish have been found in the Basin.*

*From 1991 to 1993, WQCD collected substantial amounts of chemical and biological data for the 1994 rulemaking hearing discussed in Chapter I (WQCD, 1994). The information identified the main, general source areas for heavy metals. These studies have been greatly expanded upon by ARSG and the Dept. of Interior's Abandoned Mined Land Initiative (AML) throughout the nineties.*

*The early nineties data included a wide variety of constituents because no one know exactly what might be impair aquatic life. Samples were tested for a full suite of metals. The metals that appear in concentrations that cause concern are: cadmium (Cd), copper (Cu), lead (Pb), aluminum (Al), iron (Fe), zinc (Zn), and manganese (Mn). In addition, the Colo. Dept. of Public Health and Environment under CERCLA funding did extensive sampling for organic chemicals that might affect aquatic life. They found virtually none. (Farrell Price, 1999) Results are discussed in Chapter 9.*

*Four gaging stations have been set up and maintained for the past seven years in the Basin. Two stations are located at the mouths of Mineral and Cement Creeks as they flow into the Animas River. The other two are located on the Animas River; one just above the confluence with Cement Creek and the other below the confluences with Mineral and Cement Creeks (below Silverton). This last site is referred to as A-72. Water quality data is generally collected monthly at these sites by a variety of different entities.*

*High flow and low flow synoptic (meaning same day) samplings have been done on all three major drainages – eight synoptic samplings altogether. Each synoptic sampling on Mineral and Cement Creeks was run in one day. The Upper Animas River was broken into two parts, above and below the old townsite of Eureka.*

*These sampling events involve taking flow measurements and water quality samples at fifty to eighty different locations along each main stem, bracketing incoming tributaries. All draining adits in each sampling area were sampled the next day. These efforts, involving personal from many agencies and a number of volunteers, provide the basis for determining metal loadings from different areas.*

*In addition to the synoptic samplings, eight tracer experiments have been run at various locations. Tracer experiments were run over the entire length of Mineral and Cement Creeks and significant parts of the Upper Animas River during low flow. Other tracer experiments were done on particular*

*sub-segments in the Basin.*

*For a tracer experiment, a consistent salt concentration is injected into a stream. Water samples are taken at intervals, perhaps a hundred yards apart, over a stream segment to be tested. By measuring the dilution of the salt concentration at each interval, the in-flow of water between intervals can be determined. If the flow of all surface water entering between sampling sites is measured, the groundwater inflow can be calculated. Water samples are also analyzed for metal concentrations. Therefore, sources of metals, including groundwater sources, can be precisely identified. (For a much greater description of the process, see Kimball et al, 1999.)*

*Very intense water quality sampling was done in three smaller, sub-basins in the area. Every seep, spring and draining adit that could be identified was sampled and flow measured. By comparing all of these loads to the load found at the mouth of the drainage, the relative contributions of natural versus human-induced metal loading could be estimated (Wright, 1997).*

*Different companies and agencies also did substantial sampling around potential remediation sites. Overall, a total of about 4,000 to 5,000 water quality samples have been taken.*

### ***Locating and Sampling Waste Rock and Tailings Piles***

*As part of the AML Initiative, surveys locating sites of past mining activity on public lands have been completed. Many sites lie on a mixture of public and private land.*

*A number of material samples were collected from each of approximately 250 waste rock piles (dumps) and tailings piles in the basin. These samples were tested for acid generation potential and heavy metal concentrations.*

### ***Sediments***

*Sediment samples were collected from the river bottom along the entire 110 mile length of the Animas River to help determine the sources of metal loads. (Church et al., 1997) Older sediments were also collected at strategic locations to analyze the changes in metal concentrations from pre- to post-mining periods. (Church et al., 2000).*

### ***Biological Data***

*Macroinvertebrate data has been collected twice at approximately fifty sites throughout the length of the river. The initial impact of improvements in water quality will most likely show up in macro-invertebrate counts downstream.*

*The Colorado Division of Wildlife (DOW) has done several electro-shocking fish studies in the Animas River both around Durango and in the Basin. Surveys have shown improvement in fisheries between 1992 and 1998. (See appendix 6A of UAA.)*

*Other biological studies have examined factors that might limit aquatic life including: toxicity of metal concentrations, the possible synergistic effects of copper and zinc together, toxicity of water in the pore space in the substrate, the effect of smothering of the substrate with iron and aluminum compounds, and the amount of spawning habitat.*

### ***Geology and Initial Remediation Plans***



*The Colorado Division of Minerals and Geology and U.S. Geological Survey have mapped and described many of the geologic features in the Basin that can be sources of loading and can buffer the acidity. The Division also devised initial remediation plans for most of the inactive and abandoned mine sites throughout the Basin. (Herron et al, 1997, 1998, 1999)*

*Overall a prodigious amount of effort have gone into characterizing the Upper Basin. By 2002, over \$7.2 million has been spent. Some work is still in progress. Yet with all of these resources committed to characterization, even more resources have gone into actual remediation.*

## **Updates since 2004**

Monthly water quality data (weather permitting) continues to be collected at the four stream gages around Silverton. EPA collected data to further characterize the new untreated mine drainages in upper Cement Creek in 2005-2006, and 2009-2013. Overall the ARSG water quality database includes approximately 10,000 samples and is available on the ARSG website.

Biological data has been collected in the Animas Canyon (between Baker's Bridge and Silverton) and in other locations in the upper Animas Basin for both macroinvertebrates and fish in 2005 and 2010. The fisheries data in the Animas Canyon improved from the 1990's to 2005 and then substantially declined in 2010 in terms of density and diversity of species. Fisheries data in the Animas River above Silverton which is not influenced by Cement Creek had substantially improved by 2010 from earlier sample years. (White, 2010)

Macroinvertebrate data also showed a precipitous decline in density and diversity in the Canyon from 2005 to 2010. Surprisingly, there was also a decline in South Mineral Creek in 2010. Water quality data from South Mineral Creek has always met Table Value Standards (TVS) and a good fishery exists in this sub-drainage. No water quality data has been collected in South Mineral Creek recently. Although this drainage is less of an overall priority, ARSG plans to investigate the potential reasons for the decline in macroinvertebrates in the future.

## **III. CONTROL OF NON-POINT SOURCES OF METALS**

The Colorado Division of Minerals and Geology has prepared four reclamation feasibility reports for the Upper Animas River Basin (Appendices 10A, B, C, and D of the UAA). Remediation of historical mine sites in the upper Animas will utilize the most feasible methods on a site-by-site basis according to waste characterization, site access, and disposal restrictions.

### **Surface Hydrologic Controls**

Hydrologic controls are preventative measures in that they inhibit or prevent the process of acid formation and/or heavy metal dissolution. If it is possible to prevent water from entering a mine, or coming into contact with sulfide ores or wastes, this can be the best, most cost effective approach. Here are excerpts on surface hydrologic controls from Herron *et al* (1999, p. 27):

Diversion ditches are effective where run-on water is degraded by flowing over or through mine waste, or into mine working. Diversion ditches can also be used to intercept shallow groundwater that may enter mine waste. In some cases, mine drainage can be improved by flowing through waste rock. Mine drainage must be sampled above and below a waste rock pile to determine whether the waste rock is actually degrading the water quality.

Mine waste removal or consolidation is effective where there are several small mining waste piles in an area, or where there is a large pile in direct contact with flowing water. The method is simply to move reactive material away from water sources.

Stream sealing or diversion involves moving the water sources away from reactive materials. Or sealing/lining streams to prevent surface inflows into shallow mine workings through stopes, shafts, or fracture systems. It may include lining or grouting/sealing the streambed or bedrock.

Revegetation is often used in combination with other hydrologic controls above. Revegetation by itself can be a very effective method of reducing heavy metal concentrations, particularly where much of the metals come from erosion of mining waste into a stream. Revegetation also reduces the amount of water that infiltrates a waste pile, thereby reducing leachate production. The roots of growing plants also have been shown to produce carbonates through respiration.

In addition and often in conjunction to these methods, mine waste piles may be capped and amended with neutralizing agents (*e.g.* limestone, lime, fly ash). A cap can only reduce surface moisture infiltration. Throughflow and groundwater upwelling can also occur and the impervious cap could result in increased humidity to the mine waste resulting in increased salt formation and eventual loading to nearby streams. The effectiveness of the amendment depends upon many site-specific factors.

## **Subsurface Hydrologic Controls**

Subsurface hydrologic controls are in-mine measures that inhibit or prevent the process of acid formation and/or heavy metal dissolution into the ground or surface water system. If it is possible to prevent water from entering a mine, or from coming into contact with sulfide ores or wastes, or mixing with contaminated water plumes in the workings, this can be the best, most cost effective remediation approach, because it helps prevent the problem, rather than treating its symptoms in perpetuity. The success of most hydrologic controls depends on understanding the sources and hydrologic pathways of waters that enter the mine workings and discharge from the mine workings through groundwater and surface pathways to determine how best to segregate or seal off particular water sources in the workings. Here is more discussion from Herron *et al* (1999, p. 30).

In-mine diversions are effective where clean groundwater inflows are degraded by flowing through drifts (on veins) and stopes in the mine workings. The concept is to intercept the inflows before they come in contact with metals loading source areas in the mine, thus circumventing metals contaminant production in the mine workings/ore body. The “clean” inflows are then diverted to the surface stream through a collection and piping system. Though in many cases it may not be possible to intercept all inflows before they become contaminated through contact with the ore body, it is often possible to segregate and divert much of the groundwater inflow before it mixes with the contaminated plume. This can greatly reduce the overall quantity of polluted outflow. By significantly reducing mine discharge, it may then become cost-effective and feasible to treat the segregated contaminate plume through passive or semi-passive techniques; the effluent flow is minimized, and concentration may be adjusted for optimum system performance through dilution with part of the diverted clean flows.

Grout sealing a fracture inflow zone at a

discrete location can prevent groundwater from entering the workings, using proven, existing “ring-grouting” methods and technology. The concept for this technique is to seal water inflows through a grouting program, similar to those used to seal dam foundations, and control water inflows to active underground mining operations. Chemical or cement grout is pumped under pressure into an array of holes drilled radially out from the drift in and along the plane of the water bearing fracture or fracture zones. The grout enters and seals the fracture pathways that communicate with the mine opening. If engineered and executed correctly, the water is prevented from entering the excavation, and is forced far enough back into the rock away from the mine workings so that it resumes its pre-mining course, flowing around the grout “curtain”. Depending on conditions and the layout of the workings, care must be taken to ensure the inflows are not simply diverted to a point where they enter another part of the ore body. Ideally, the grout curtain would be in position where no other lower or upper levels are nearby, and where numerous small fractures or one discrete structure is draining groundwater into the workings along a relatively short section of drift.

Bulkhead seals are another type of preventive or “source control” measure. The concept is that geochemical and flow equilibrium will be reached in the groundwater, whereupon anoxic conditions in the flooded workings will prevent or reduce dissolution and transport of heavy metals. Bulkhead seals are designed to prevent discharge to surface water through the adit opening by blocking the flow with an engineered hydrologic plug, flooding the mine. For most inactive mines, bulkhead seals are expensive and require considerable geologic and engineering investigation and characterization. Sites that have simple geology, sound rock, and limited subsurface workings may be amenable to this approach.

Sometimes water inflow into mines can be reduced from remedial measures implemented outside of the mine workings. For example, grouting or sealing fracture areas may be done from the surface. A mine near Eagle, Colorado, installed a well near a fracture zone to lower the water table. But all these hydrologic controls may not be enough or may be almost impossible to implement depending on specific characteristics of a site. Discharge from adits may need to be treated. There are a wide range of options, all of which have positive aspects and drawbacks. Generally, treatment involves raising pH levels if they are low and precipitating metals.

## **Passive Treatment Techniques**

Passive treatments have received a lot of attention from mine-drainage remediation specialists because of relatively low costs, low maintenance, and effectiveness. Here is a summary of passive treatment techniques from Herron *et al* (1999, p. 28):

Anoxic limestone drains are the simplest method of introducing alkalinity into mine discharges. Anoxic limestone drains (ALD) are constructed by placing coarse limestone (3/4” – 3”) inside an adit or in a fully sealed trench outside a discharging mine. In order for an ALD to function properly, the mine discharge must be devoid of oxygen. In the absence of oxygen, limestone will not become coated by iron and other metal hydroxides, which can shorten the useful life of limestone. In addition, the mine drainage should be relatively low in dissolved aluminum. Aluminum has been shown to precipitate in ALD’s, causing plugging. It is theorized that very coarse limestone (4”-6”) should provide large enough pore spaces to minimize or prevent clogging by aluminum. The disadvantage of using larger limestone is the reduced surface area to react with the mine drainage. After the mine drainage exits the ALD, aeration causes precipitation of metals. The increase in pH due to ALD’s is site specific, but

generally does not exceed two standard units.

Settling ponds are often overlooked as an effective treatment method. Settling ponds are particularly effective for treating near neutral mine drainages high in total suspended solids (TSS). Aeration of a near neutral pH mine drainage by means of a series of drops, followed by a settling pond can effectively remove iron and other metals that co-precipitate with iron. Settling ponds should be designed for a 24-hour or greater retention time wherever possible.

Sulfate reducing wetlands are often called bioreactors. These systems treat water through bacterial reduction of heavy metals. Sulfate reducing bacteria (SRB) utilize the oxygen in sulfates for respiration, producing sulfides. The sulfides then combine with heavy metals to form relatively insoluble metal sulfides. The bacteria derive their energy from a carbon source such as cow manure or mushroom compost. There are many other substrates that are an acceptable source of carbon, but most have a low hydraulic conductivity that can result in short circuiting of the system by formation of preferential flow paths. Sulfate reducing bacteria cannot survive in drainages with pH below 4.5. Highly acidic drainages will require a pH increase before the effluent enters the bioreactor.

Sulfate reducing wetlands should generally not be constructed near population centers. These systems commonly produce excess hydrogen sulfide, which can cause undesirable odors up to three miles from the system. When initially started, organics in the substrate discolor the treated water for several months, making water quality appear, to the layman, to be worse than that entering the system.

Aqueous lime injection is a passive method to introduce neutralizing agents into mine drainage. This system requires a clean water source. Clean water is passed through a pond containing neutralizing agent, then the high pH effluent is mixed with the mine drainage before it enters a settling pond. This system can be cost effective if the alkaline wastes such as kiln dusts or fly ash are available. Although still in the experimental phase, the method holds promise for some mine sites. Neutralizing materials may also be injected into stopes and drifts.

Limestone water jets are an aerobic method of accelerating the dissolving of limestone. In situations where mine drainage flows down a steep slope, the discharge can be piped, and the resultant head can produce a high-pressure water jet. The high-pressure jet can be either sprayed onto loose crushed limestone, or passed upward through a vessel containing limestone. In both situations, the limestone does not become coated because of abrasion by the water jet, and agitation of the surrounding clasts. The system using a vessel can result in higher alkalinity in the effluent due to greater abrasion. Both system types are in the experimental phase.

Oxidation wetlands are what most people think of as “wetlands”. They differ from sulfate reducing systems in that metals are precipitated through oxidation, and aquatic plants must be established. This treatment method is applicable where the pH of mine drainage is approximately 6.5 or higher, and where metals concentrations in the drainage are primarily a problem during summer months. Aeration is an important part of the system. The plant materials provide aeration and, when they die, provide adsorption surfaces, along with sites for algal growth.

Aeration is best used where the mine drainage pH is about 6.5 or above. Aeration promotes

metal precipitation through oxidation processes. Aeration can be accomplished by mechanical means, or simply by channeling the drainage over rough slopes. Mechanical methods require some source of power, which may be generated through wind, solar cells, or hydropower. Aeration methods normally include a settling pond below the aeration component.

Mechanical injection of neutralizing agents involves a powered mechanical feeder/dosing system for dispensing neutralizing agents. This type of system requires frequent maintenance, may produce significant quantities of metal sludge, and should be considered “semi-passive.” Power for the feeder can come from wind, solar, or hydropower. At the Pennsylvania Mine in Summit County, a turbine running in the adit discharge stream demonstrated that hydropower is practical in some situations. Mechanical systems are generally considered only where there are no options for truly passive alternatives. Any high pH material can be used in this type of system. Because of cost effectiveness and sludge characteristics, the most common neutralizing agent is finely ground limestone.

Dilution is often overlooked as a treatment method. It can be a cost effective method of treatment, because the neutralizing agent is simply uncontaminated water. Clean water is mixed with the mine drainage in a settling pond, and the resultant pH increase initiates precipitation of metals. A drawback to this method is that the percentage of metals precipitated is significantly less than other methods. Metal removal is site specific, but generally less than 50%. This method is most effective in removing iron, aluminum, copper, cadmium, and lead, but has only slight effectiveness for zinc and manganese.

Electro-kinetics is a newer semi-passive method to remove metals from mine drainage. There are several forms of this treatment currently being developed. The electro-kinetic method discussed in this report uses a low-maintenance, self-regulating resin to remove metals from mine discharge. Different metals can be separated by using ion specific resins. Electricity is used to strip metals from the resins, producing sludge, and allowing re-use of the resin.

Land application is a method designed to use natural metals attenuation processes in soil and subsoil to remove metals. Plant uptake, evaporation and transpiration, and soil exchange capacity act to tie up and remove metals. This method is most effective where mine discharge can be spread over a large area to infiltrate into relatively thick soils or unconsolidated deposits. Drainage should be neutral or near neutral to avoid plant toxicity. This alternative is also effective for discharges with high iron and/or aluminum, where pH is approximately 4.5 or above.

In addition to these passive and semi-passive techniques, there are active systems that operate in much the same manner but have more mechanical mechanisms and need more maintenance.

#### **IV. SETTING GOALS FOR LOAD REDUCTIONS**

In order to set goals, ARSG had to characterize sources of metal loading, determine the feasibility of reducing those loads, and estimate how those load reductions would improve water quality. This section describes the approach used by ARSG.

## **Characterization and Remediation Ranking and Prioritization**

The Colorado Division of Mineral and Geology, with direction from ARSG, has taken a first cut at estimating the feasibility of reclamation for 140 sites (some of which have multiple features) in the Upper Animas Basin. Their four reports – one for Mineral Creek, Cement Creek, Upper Animas above Eureka, and Upper Animas below Eureka (Appendices 10A, B, C, and D of the UAA) - describe sites, diagram sites, list results of water quality and leachate data (from mine waste piles), and recommend remediation techniques. The reports are quite extensive yet most sites will require more specific process and design engineering before construction begins.

In conjunction with and addition to these reports, the ARSG Prioritization committee characterized and ranked 159 mine waste sites (waste rock piles and mill tailings) and 174 draining adits relative to one another. While ranking of sites was based upon analytical data determined through sampling, testing and monitoring, the sites were prioritized by combining ranking information with more subjective attributes. Various weights were placed on different attributes of a site depending on which attribute was thought to be relatively more important than another. This enabled the group to focus remediation towards achievement of specific goals based upon available technology, funding, and property owner cooperation. Spreadsheets containing this information were the basis for developing the remediation scenarios and calculating potential reductions. While ranking was completed during 2000, prioritization was intended to be periodically revisited.

### ***Mine Waste Piles***

Mine waste piles were characterized relative to their potential impact on the environment. Certain attributes of each site are listed on the rank and prioritization spreadsheets (UAA Appendix 10F). Potential for contribution of metals and acidity to nearby streams was determined by leachate tests. Ten to twenty samples were taken from various locations of the upper six inches of the surface on each mine dump or tailings pile. The samples were mixed to form a composite sample. The composite sample, 150 milliliters (ml.), was mixed vigorously with 300 ml. de-ionized water (2:1 ratio). After allowing clay particles to settle, part of the sample was tested for total acidity, pH, and conductance. The remainder was acidified to determine metal content. (See Herron *et al.*, 1999, for more details on the process.) Some data also exists for 20:1 EPA method 1312 Leach test and Modified 1312 leach tests for several sites. This data was not included in the ranking process because it cannot be compared to the 2:1 leach test. In addition, USGS has done some leach testing using yet another sampling and analysis method.

Mine wastes were ranked by metal contributing potential for zinc, copper, cadmium, lead, manganese, aluminum, and iron and pH as determined by the 2:1 leach test. For example, the waste with greatest zinc leachate concentration is ranked number one for zinc. The same site may be ranked number five for lead if it has the fifth highest amount of lead leachate concentration, and so forth. In addition, weighting factors have been assigned for the metals analyzed. Aluminum and iron are considered limiting factors but the sources of these metals are overwhelmingly associated with natural features and processes. In addition, they will automatically be reduced by any treatment method. Reductions may not even be beneficial since their presence downstream may be desirable for scavenging Zn, Cd, and Cu from solution by sorption to their precipitates. Aluminum and iron were given a weighting factor of one.

Manganese and lead were both given a weighting factor of two because they generally have a moderate potential as limiting factors, while their sources are more specifically identified with mine features than those of iron and aluminum. Lead falls from solution readily in the Animas watershed and will probably not be a limiting factor if treatment for other metals progresses. A handful of sites appear to be high contributors of manganese.

Copper, cadmium, and zinc have high

potential as limiting factors throughout the basin and tend to be highly correlated to mine and/or mill features. They come from a multitude of sites. These are given the highest weight factor of three.

The other weighted factor, pH, is a strong limiting factor in Mineral and Cement Creeks, but is not as significant in the Animas River above Silverton. Some treatment methods may result in increased pH but much of the low pH is thought to be the product of natural geological processes. It is given a weighting factor of two.

To complete ranking, each of the seven metals plus pH were multiplied by their respective weighting factors then added together for each mine waste site. The resulting sum is a measure of the severity of total loading potential. Sites were then ranked for remediation by the weighted sum; the lowest number is given the highest priority. The prioritization was done for each of the three sub-basins and for all the sub-basins lumped together (Combined Rankings). That way remediation can be targeted for specific segments, depending upon in which sub-basin they lie, or by their collective impact on the Animas River below Silverton.

In addition to the leach test results, many other characteristics are listed on the spreadsheets for the dumps. These are also important considerations in prioritizing sites for remediation, but have not been included as part of a mathematical sum. These include:

- ◆ site names and locations,
- ◆ the size of planer surface areas of dumps,
- ◆ volume of material where estimated by DMG,
- ◆ distance to ephemeral streams,
- ◆ distance to perennial streams,
- ◆ biological potential of nearby streams (*i.e.* potential presence of aquatic life),
- ◆ orientation (direction) of slope (indicates when snow may melt off),
- ◆ whether or not a vegetative kill zone exists below,
- ◆ relative steepness of the site,
- ◆ ease of access,
- ◆ whether or not acid mine drainage runs over or through the dump,
- ◆ potential remediation that might be applied,
- ◆ rough estimate of cost of remediation.

Some of these characteristics require additional explanation. The planer surface areas of dumps were estimated from 1998 USGS Orthophotographic Quadrangle Maps. They are considered to be overestimates because surface disturbances related to roads and portal cut banks often could not be visually distinguished from the wastes. Generally, the entire disturbed area was distinguishable and therefore measured. On the other hand, sites smaller than 80 to 100 square meters were not included because of resolution difficulties. Although there are many small prospects that fit this category, prospects seldom contain high mineral content (otherwise they would have been more extensively mined). The assumption is that the overestimate of the larger waste sites is countered by not estimating the prospect sites. Distances to ephemeral and perennial streams were also estimated using the Orthophotographic Quadrangle Maps.

Several characteristics are given a relative rating. Biological potential (of immediate receiving stream) is divided into three categories; low, medium, and high. Likewise, steepness is rated, flat, moderate, or steep. Access is rated 1 through 4, with 1 being easy and four being very difficult.

Potential remediation techniques are divided into five categories: capping, amending with neutralizing agents, removal and cleanup, hydrological controls (such as drainage ditches), and consolidation of dumps. The ARSG Prioritization Committee, which is made up of five professionals with extensive experience in implementing mining remediation, estimated typical rates of metal

removal for each technique: capping – 25%, amendment – 10%, removal – 90%, hydrologic controls – 20%, and consolidation –10%. These percentages are considered additive if more than one technique is applied to a site. The reduction rates are also considered an average rate for the method over time. Some sites may provide better results; others worse. The spreadsheets show which techniques might be best applied to particular sites.

Several sites are currently listed as "no action". After careful evaluation by the Prioritization Committee, these sites were considered having a low potential of contributing metal loads to receiving streams. There are also numerous sites that were identified through Orthophotographic Quadrangle Maps as disturbed areas and have been included on the spreadsheets. Leach test samples were not collected from these sites because best professional judgment determined that metal and pH contributions would be insignificant to receiving streams.

Estimated costs for remediation are based on best professional judgment and are site specific. Administration and contingency costs are not included for individual sites but are added to the overall costs of the remediation scenarios described in the next chapter. Disposal costs of any removed material have not been included. Four cost ranges have been applied: under \$20,000, \$20,000 to \$100,000, \$100,000 to \$500,000, and greater than \$500,000 in 2001 dollars. The specific remediation estimates for particular sites are shown on the spreadsheets.

## ***Draining Adits***

Adits have been characterized in method similar to dumps. The results are listed on rank and prioritization spreadsheets for each sub-basin and the complete Basin in Appendix 10F of the UAA. An attempt was made to sample all draining adits during both high and low flow time periods. Flow measurements were taken at the same time as samples. Sampling was coordinated by the Division of Minerals and Geology and ARSG (See Appendices 10A, B, C, and D - UAA). Due to the large number of adits, over 170 (some being quite remote and/or not initially located), a few adits were missed or sampled only at high or low flow periods. High flow samples were also not possible at all sites because of inaccessibility due to deep snow. Some adits had no or unmeasurable flows at low flow. ARSG is continuing to fill in the missing data.

Water samples were collected from adits in the Mineral Creek drainage in 1995-1996, in the Cement Creek drainage in 1996-1997, in the Upper Animas drainage above Eureka in 1997-1998, and in the Upper Animas below Eureka in 1998-1999. All adits were sampled the same day in each sub-basin. High flow samples were taken in late June or July. Low flow samples were taken in September or October. Additional water quality samples were taken at a number of sites by other agencies and companies participating in ARSG. Wherever multiple high flow data exist for a particular site, the data have been averaged. Multiple low flow data were also averaged. All samples were taken at the portal entrances.

Adits were ranked in the same fashion as mine waste, using seven metals, pH and the same weighting factors for each metal. Interestingly, when this ranking was compared to a ranking where the weighting factors were removed, the top twenty five adits in the whole Upper Animas Basin remained the same and order of those twenty five changed little. The weighting factors made little difference in the overall results.

Adits are also ranked on the spreadsheets for high flow, low flow, and the combination of high and low flows in terms of metal loading and pH. It depends on what are the analytical purposes and goals of remediation efforts.

As with mine waste, other characteristics that may be important to prioritize adits for remediation are included on the spreadsheets such as:

- ◆ site names and locations,



- ◆ flow rates during high flow and low flow,
- ◆ dates of sampling if only one sample was taken during high or low flow,
- ◆ proximity of receiving streams,
- ◆ biological potential of nearby streams (*i.e.* potential presence of aquatic life),
- ◆ orientation (direction) of slope (indicates when snow may melt off),
- ◆ whether or not a vegetative kill zone exists below,
- ◆ whether or not acid mine drainage impacts dumps below the adit,
- ◆ ease of access,
- ◆ potential remediation that might be applied,
- ◆ potential effectiveness of remediation,
- ◆ rough estimate of cost of remediation.

The proximity of receiving stream is rated relatively: instream, near, medium, or far. Biological potential of the receiving stream is rated high, medium or low. Ease of access has a relative scale of 1-4 with 1 meaning easy access.

As with mine waste, the potential remediation technique for each site was based on professional judgment of the ARSG Prioritization Committee. The techniques are categorized as bulkhead seals, source controls, passive treatment and active treatment. Hydrologic controls like bulkhead seals and source controls are more desirable because there is minimal operating and maintenance costs. Source controls are means of inhibiting water from leaching metals from underground workings, either by preventing water from entering mines (*e.g.* re-routing surface waters, pressure grouting inflows) or by collecting in-flowing water before it reaches mineralized surfaces and transporting the water back to surface in an inert conveyance.

Where conditions are perfect, such as in deeply situated mine workings where water is entering far from the surface and when the rock has only minimal, small fractures, complete reduction of loading to streams might be expected using bulkhead seals. But this is an unusual situation since many adits are shallow in depth, and the surrounding rock is often highly fractured, naturally or from mining activities. Then water will find alternative pathways around the bulkhead seal.

Finding and gathering in-flowing water can be difficult and expensive. First the in-flow must be located by geophysical methods, tracer dye injections, or visual examination from the surface and within the mine. Seldom can all in-flowing water be accounted for, particularly if the underground workings include abandoned stopes and raises. As result of these difficulties, ARSG has determined that on the average, 50% reductions for these two methods would be optimistic for the typical mines and conditions presently known in the Upper Animas Basin.

The other two remediation categories are passive and active treatment. Passive treatment generally requires continued long-term maintenance and, on average, will be less effective than hydrological controls. There is a wide range of passive treatment methods available and often two or more methods can be built into the treatment of a single mine drainage. Some treatment methods (*e.g.* settling ponds) may only remove a small percentage of a single metal whereas a complex system may remove varying amounts of several metals. Given the high elevation, severe winters, high precipitation, steep slopes, and need for continued maintenance and medium renewal, it is estimated that passive treatment systems may average 30% reductions over an extended (20 year) period.

There are several methods of active treatment available. All require large initial capital outlays and annual expenditures for operation and maintenance in perpetuity. This category is considerably the least desirable approach, although potentially the most effective at reducing metal loading. Active treatment plants are generally designed for reduction of specific metals. As such, they can be very effective for the metal of concern. But it is to be expected that there will be lower percentage reductions for other metals. An 85% average reduction of all metals is anticipated using active

treatment methods.

In some cases, one remediation method might be tried, such as source controls, but more metals may need to be removed. After the source controls are implemented, passive treatment may be needed. The potential for this additional treatment is noted under Phase 2 of the treatment methods on the spreadsheets. Phase 1 may not be successful or only minimally. Therefore Phase II costs are a summation of the two phases. Several sites are currently listed as "no action". After careful evaluation by the Prioritization Committee these sites were considered having a low potential of contributing metal loads to receiving streams.

As with the mine waste characterization, estimated costs for remediation are based on best professional judgment and are site specific. Administration and contingency costs are not included for individual sites but are added to the overall costs of the remediation scenarios described in the next chapter. Four cost ranges have been applied: under \$20,000, \$20,000 to \$100,000, \$100,000 to \$500,000, and greater than \$500,000 in 2001 dollars. Some sites were difficult to fully assess and available remediation methods did not appear to be practical to apply, particularly without further investigation. For these sites, costs reflect the next steps for further evaluation but do not include estimated percentage reductions since the most appropriate remediation method is not known at this time. The specific estimates for all sites are shown on the spreadsheets.

The rank and prioritization spreadsheets were designed to focus remediation on locations where the largest benefits could be realized for the effort and resources expended. They were not developed specifically for the UAA and are expected to change as more information becomes available. However, they are very useful for setting up different scenarios describing what metal reductions may be possible and at what cost, if a certain number of sites were remediated.

## ***Loading from the Largest Adit and Mine Waste Sources***

The adits have been ranked, using the weighting factors discussed above, on the basis of both high and low flow loading of seven metals plus pH. Most high flow samples were obtained in June or July, while low flow loads were obtained in September or October. These figures may overestimate low-flow loading since early fall stream flows had not yet dropped to levels seen in winter months. Loads from the Kohler, Bandora, North Star, and Evelyn mines were sampled frequently.

Selection of sites to be included for possible remediation is based upon the combined rankings of all sites within the Upper Basin (Appendix 10E - UAA). Many sites were previously categorized as "no action" because of their low total contributions and remoteness and/or low concentrations. The loading from the top ranking 33 adits, including a few large loaders lacking either a high or a low flow sampling datum, are shown in Table 11.1 in the UAA. This table has been modified and is shown as Table 1 below. These are loading figures from 2001 and do not include any potential reductions. Eighty nine percent of the loading from all adits comes from these top 33 sites.

Mine waste piles have been ranked in a similar fashion as adits including the same weighting factors, except that they are ranked by metal concentration determined by the leach test instead of load (Appendix 11A - UAA). Table 11.2 in the UAA lists the top 26 mine waste sites plus an additional six sites which were added because of their large size and therefore potential for significant load contributions. This table has been modified and is shown as Table 2 below. Leachate concentrations presented in Appendix 10E of the UAA were converted to "potential loads". The annual load contributed from waste rock site in Table 11.2 was estimated by multiplying the concentration from the leach test of the waste rock times the surface area of the pile times the average annual runoff from the basin expressed as depth (29 inches). The potential load figures do not include any potential reductions.

The 32 waste sites listed contribute 90% of the estimated load from all 158 sites. Units are in pounds per year as opposed to pounds per day used for adits. Estimated loading from mine waste is

much smaller than from adits. Approximately eighty-five percent of the mine-related annual metal load in the Upper Animas Basin is from adits, and fifteen percent is from mine waste.

As with adits, the appropriate site treatment and corresponding load reductions are based on professional judgment. Again, the estimated costs of remediation fall into the same four categories used for adits. The costs listed in Table 11.2 are the mid-point of the ranges of each category applied to the particular site.

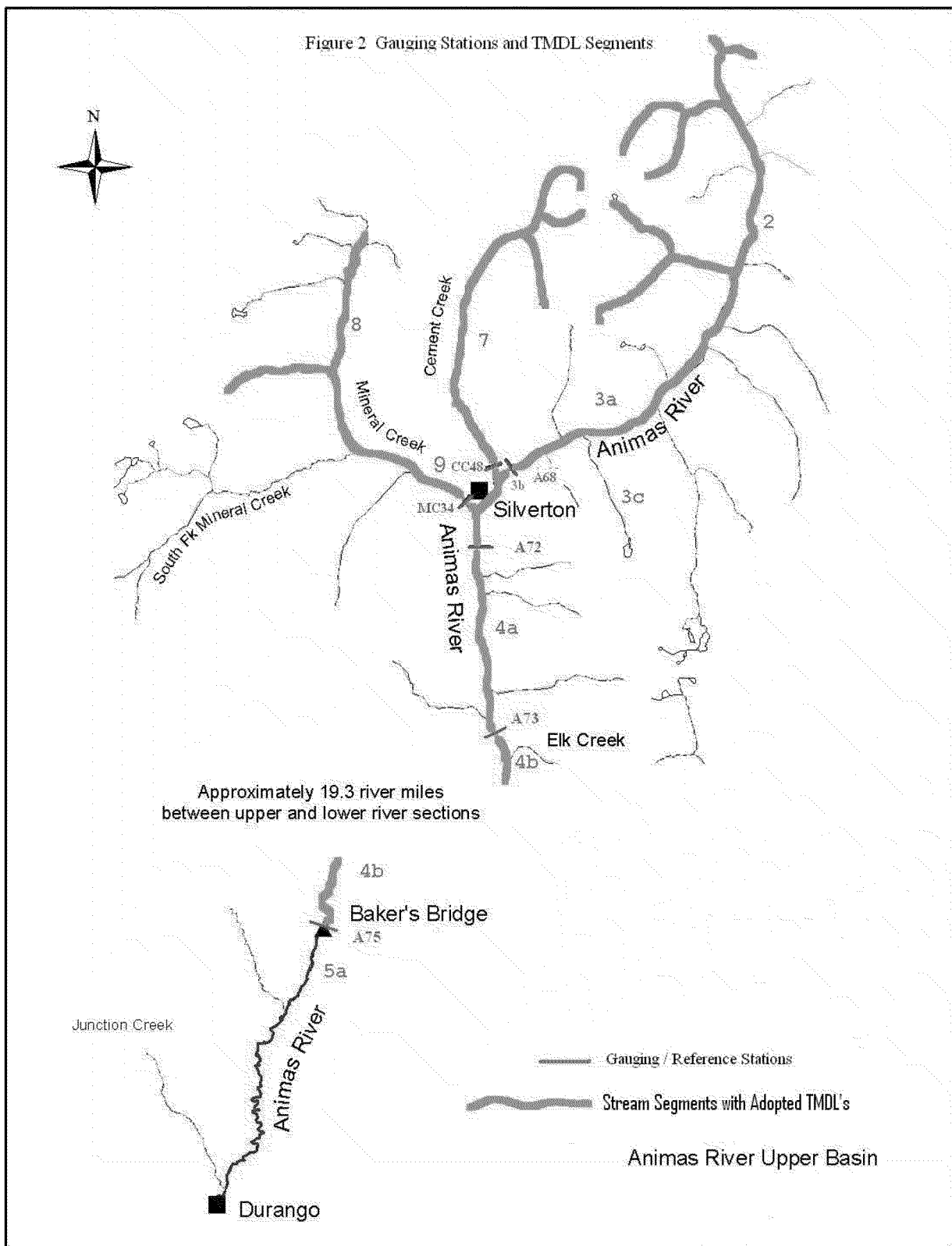
Sites with CPDES or reclamation permits are not included in these tables. It is assumed that required best management practices and/or treatment at these sites are already in place.

### **Development of Water Quality Standards as Goals**

In the UAA, the potential metal load reductions due to remediation from the 33 draining adits and 32 mine waste sites were subtracted from the existing metal loads in Mineral and Cement Creeks and the Animas River. This assumed that load reductions at mine sites would directly result in equal load reductions instream. From the reduced load estimates, instream water quality concentrations were calculated and became the basis for recommendations for monthly numeric water quality standards in the Upper Animas Basin. These recommendations were slightly altered during the WQCC's process in adopting water quality use classifications and standards in 2001. The standards serve as a quantitative goal to attain through remediation.

Twenty-nine TMDL's were developed by WQCD using the remediation scenarios in the UAA and the adopted water quality standards. Figure 2 shows the segments with TMDL's and shows the locations where monthly water quality monitoring occurs.

**Figure 2 – Water Quality Monitoring Locations and TMDL Segments**



### *Changes since the 2001 Rulemaking Hearing*

As noted in the introduction, the higher water table in upper Cement Creek has created a number of new or greatly increased discharges beginning in 2003. Four adits in particular have become the top mining-related metal sources in the basin. In fact, the four adits – Gold King #7 level, Red & Bonita, Mogul, and American Tunnel - produce approximately as much metal loading as the original 33 adits noted above. These four adits have been added to the initial 33 adits in Table 1 which is an adaptation of Table 11.1 from the UAA.

Another addition to the original UAA table is newer loading numbers for the Koehler and Mogul. Bulkheads were installed in both these adits after the UAA. In 2011, the rock surrounding the Koehler bulkhead was grouted under a 319 grant to reduce seepage. This project appears to be very successful, but ARSG is still collecting data, and so the current metal load from the Koehler is not listed on the table. The Mogul bulkhead has not curtailed flow effectively, and this adit has been affected by the higher groundwater table.

Table 2 is an adaptation of Table 11.2 from the UAA. Two mine waste sites have been added, the San Antonio and Carbon Lakes. Another mine waste site in the Mineral Creek watershed, the Silver Ledge, was considered significant and was remediated in 2011, but is not on the table. All the sites on both tables that are highlighted in yellow have had at least some remediation, mostly funded through the 319 NPS program. Remediation of the Bullion King mine waste is scheduled for summer of 2014, and hopefully the Clipper mine waste will be done in 2013. Many more mine waste sites have been addressed than draining adits, even though the adits are much bigger sources of metal loading. Metal loading from adits is estimated to be more than nine times greater than from mine waste. Funding and the lack of liability protection under some sort of Good Samaritan provision have severely limited ARSG's ability to remediate draining adits.

**Table 1 - Metal Loads from Selected Adits in the Upper Animas Basin**

			High Flow						Low Flow					
Mine	%Removal	\$ 1000's	Al	Cd	Cu	Fe	Mn	Zn	Al	Cd	Cu	Fe	Mn	Zn
Cement Creek														
Gold King 7 level			98.7	.186	17.6	360	73.9	71.3	60.1	.162	15.4	224	86.1	60.3
Red & Bonita			13.3	.13	.081	318	118	56.6	13.5	.136	.021	356	129	61.9
American Tunnel			8.6	.004	.011	215	74.8	29.2	7.0	.003	.008	192	66.0	26.3
Mogul (2009)			3.1	.05	.04	32.0	27.2	29.1	2.0	.034	.017	21.0	19.1	21.1
Mogul	80%	1000	1	0.04	1.7	14	4	2	1	0.02	0.7	5	1	3
Silver Ledge	50%	300	25	0.09	0.6	222	33	15	4	0.03	0.0	56	11	3
Grand Mogul	0%	60	15	0.15	5.3	33	10	27	1	0.01	0.2	0	0	1
Mammoth	30%	60	1	0.00	0.0	14	2	8	1	0.00	0.0	16	2	0
Anglo-Saxon	30%	60	0	0.00	0.0	15	10	2	0	0.01	0.0	15	5	1
Joe & Johns	30%	300	0	0.00	0.2	1	1	1	0	0.00	0.0	1	0	0
Big Colorado	50%	300	1	0.00	0.0	3	3	0	1	0.00	0.0	6	0	0
Porcupine	30%	60	0	0.00	0.0	14	5	1	0	0.00	0.0	10	5	1
Evelyn	50%	1000	1	0.00	0.0	2	0	0	2	0.00	0.0	3	0	0
Lewis property	50%	60	0	0.01	0.4	2	0	1	0	0.01	0.4	2	0	1
Total Cement Creek			44	0.29	8.3	320	68	57	10	0.07	1.3	113	25	12
Mineral Creek														
Koehler (2005)			13.4	.1	5.8	63	14.6	37.9	7.1	.1	2.5	51	4.2	15.4
Koehler	50%	60	33	0.36	30.7	321	10	91	28	0.25	28.3	264	8	78
North Star	50%	300	0	0.02	0.1	6	16	4	1	0.02	0.2	6	11	3
Junction Mine	50%	300	13	0.07	2.2	126	3	14	0	0.00	0.1	3	0	0
Bandora Mine	30%	60	0	0.04	0.1	5	4	10	0	0.02	0.0	2	2	4
Upper Bonner	50%	300	1	0.00	0.0	1	1	1	2	0.01	0.0	2	1	1
Ferrocete Mine	50%	300	2	0.00	0.0	31	5	1	3	0.01	0.0	32	7	1
Paradise	0%	60	28	0.00	0.1	246	20	2	28	0.00	0.1	246	20	2
Brooklyn Mine	30%	300	1	0.01	0.2	8	2	2	1	0.01	0.2	8	2	2
Bonner Mine	50%	300	1	0.01	0.0	1	1	1	2	0.00	0.0	2	1	0
Lower Bonner	30%	300	1	0.00	0.0	1	0	0	2	0.00	0.0	2	1	1
Little Dora	50%	300	1	0.33	0.9	5	653	48	0	0.00	0.0	0	2	0
Total Mineral Creek			81	0.85	34.3	751	715	175	65	0.31	28.9	566	54	93
Animas above Eureka														
Vermillion Mine	50%	300	0	0.04	0.2	2	1	9	0	0.01	0.1	1	0	3
Columbus	50%	300	1	0.01	0.3	3	0	9	0	0.02	0.1	1	0	4
Lower Comet	0%	10	2	0.00	0.1	2	2	1	2	0.00	0.0	1	1	1
N side of Calif. Mtn.	30%	60	4	0.01	0.0	1	5	2	4	0.01	0.0	1	5	2
Sound Democate	50%	60	0	0.00	0.1	0	4	1	0	0.00	0.0	0	2	0
Mountain Queen	50%	300	0	0.00	0.2	1	0	1	0	0.00	0.1	0	0	0
Silver Wing	30%	0	0	0.00	0.1	0	0	0	0	0.00	0.3	1	1	1
Bagley	30%	300	0	0.01	0.0	0	13	7	0	0.01	0.0	0	6	3
Senator	30%	300	0	0.00	0.0	21	7	0	1	0.00	0.0	23	14	2
Total Animas above Eureka			8	0.08	1.0	30	33	29	8	0.06	0.7	29	29	15
Animas below Eureka														
Royal Tiger	50%	300	5	0.04	0.8	0	3	7	0	0.00	0.1	0	0	0
Pride of the West	30%	60	0	0.01	0.0	0	0	3	0	0.01	0.0	0	0	2
Little Nation	30%	300	0	0.00	0.0	9	2	1	0	0.00	0.0	4	1	0
Grand Total Pre-2001			138	1.29	44.5	1110	822	271	83	0.45	31.0	712	109	124
Total CC Increase (2009)			123	.33	16.0	911	290	184	81.6	.315	14.8	788	299	167
Sum of Two Lines Above			261	1.62	60.5	2021	1112	455	165	.765	45.8	1500	408	391

**Table 2 - Metal loads from Selected Mine Waste Sites in the Upper Animas Basin**

Load in pounds per year									
Site Name	Acres	% Reduction	Cost \$1000	Al	Cd	Cu	Fe	Mn	Zn
Cement Creek									
Galena Queen	1.09	90	300	154	36.8	832	6,895	0.0	6137
Kansas City #2	0.46	40	60	159	7.1	39	3,979	0.0	1172
Hercules	1.26	90	300	163	30.6	168	6,712	0.0	4711
Upper Joe & Johns	0.02	40	300	2	0.1	2	19	0.0	23
Grand Mogul - East	0.53	35	300	47	2.0	29	745	0.0	385
Kansas City #1	0.48	40	60	82	1.2	19	1,618	0.2	282
Black Hawk	0.20	50	60	82	0.5	6	124	0.1	108
Lead Carbonate	0.62	55	300	120	0.8	27	1,228	0.0	179
Henrietta 3	0.86	20	60	217	0.7	107	4,972	0.0	113
Ross Basin	0.15	10	60	9	0.3	18	234	0.0	49
Lark	0.66	90	60	18	0.8	40	886	0.0	168
Pride of the Rockies	0.05	45	60	7	0.1	0	383	0.1	7
Henrietta # 7	1.19	40	300	101	0.8	25	1,685	0.0	159
Mogul	1.16	35	300	51	1.2	32	942	0.0	261
Cement Creek Total	8.72			1,210	83.1	1,343	30,421	0.5	13,754
Mineral Creek									
Brooklyn	0.25	90	300	58	0.8	8	993	117	118
Bullion King: Lower	0.86	90	300	641	6.0	14	9,945	190	629
Upper Browns Trench	0.11	40	10	27	0.1	8	198	3	9
Congress Shaft	0.35	40	60	11	0.2	16	109	11	20
San Antonio	.33	40	60	211	4	139	3826	13	532
Brooklyn Upper	2.57	20	60	661	3.1	38	9,909	176	163
Upper Browns	0.51	90	60	82	0.3	5	1,610	6	25
Little Dora	1.39	30	300	94	0.4	43	452	471	66
Brooklyn Lower	0.86	20	60	110	0.6	9	672	122	105
Mineral Creek Total	7.23			1,895	15.5	281	27,714	1,108	1,667
Animas above Eureka									
Ben Butler	0.34	40	300	28	0.8	8	225	1	165
Silver Wing	1.21	50	60	98	1.0	123	393	172	131
Tom Moore	0.19	90	60	15	0.3	1	8	43	73
Eagle	0.07	90	60	1	0.1	1	0	7	18
Lucky Jack	0.70	90	60	16	0.6	3	14	32	95
Animas above Eureka Total	3			157	2.8	136	639	256	482
Animas below Eureka									
Clipper	0.09	90	60	6	0.2	7	80	57	70
Buffalo Boy	0.38	90	60	17	0.8	24	13	73	141
Ben Franklin	0.37	90	60	81	0.4	13	612	99	95
Caledonia	0.57	30	60	23	1.0	15	1	50	255
Sunnyside	2.50	90	1,000	40	2.3	10	0	536	664
Animas below Eureka Total	4			168	4.6	69	706	815	1,224
GRAND TOTAL	22			3,219	102	1,691	55,655	2,167	16,595

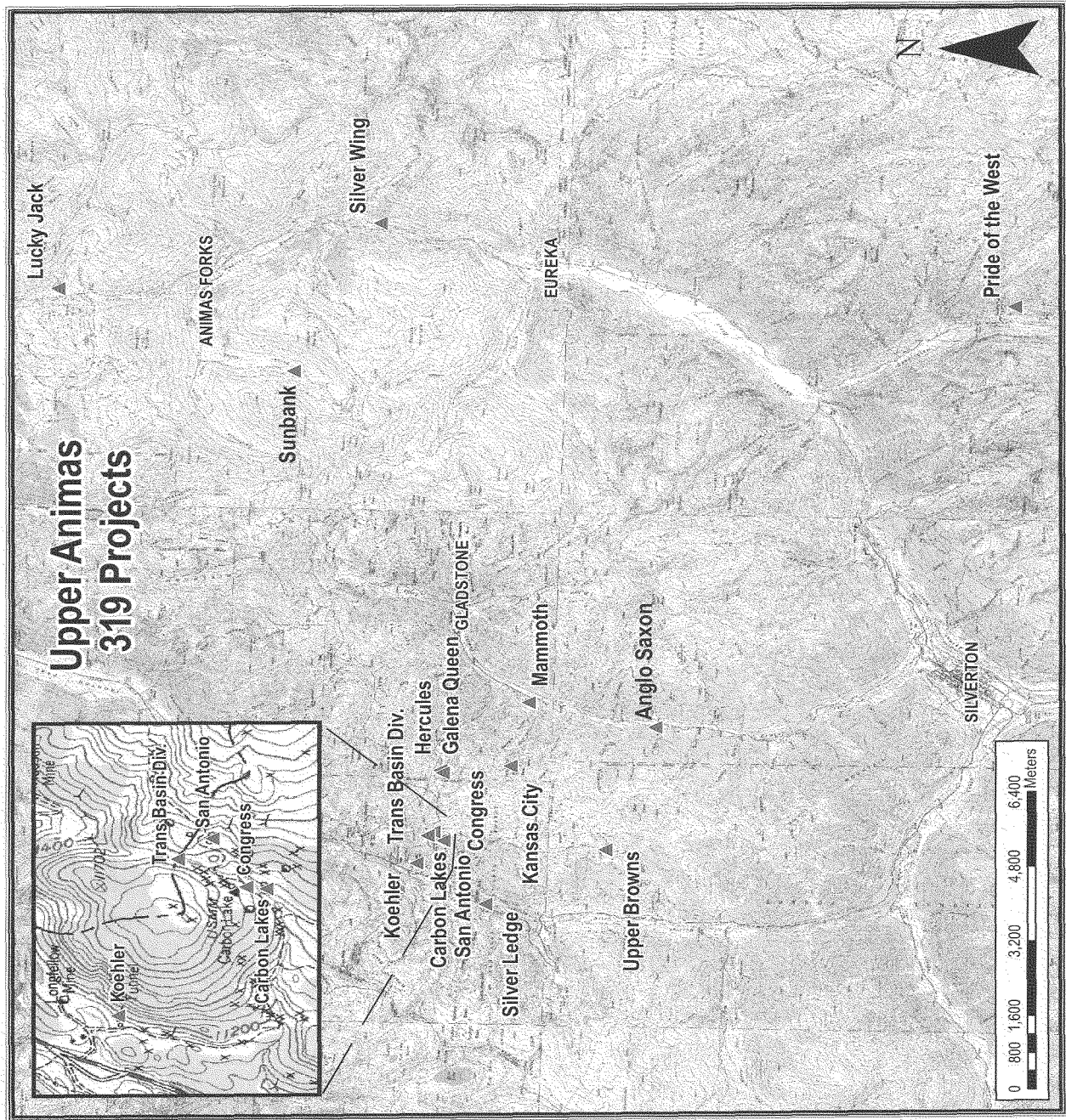
## **V. REMEDIATION IN THE UPPER ANIMAS BASIN**

In addition to the highlighted sites above, a number of other remediation projects have been completed, many of which were done by Sunnyside Gold Corp. under the consent decree. Some projects were completed before the table was developed. Others were not necessarily priorities for ARGIS but were priorities for federal land management agencies. All told, about 60 projects have been completed in the Upper Animas Basin. They are listed in Appendix B. Approximately eighteen projects utilized 319 funds. A map showing the location of those projects is Figure 3 below.

**Figure 3 – Map of the 319 Projects in the**



# Animas River Basin



Of the 60 total projects, at least 30 are surface hydrologic control projects including removal of mine waste material. There are also seven subsurface hydrologic control projects, all using bulkhead seals. Five different passive techniques are in use or have been used in the Upper Animas Basin including injection of a neutralizing agent, anoxic drains, a wetland, a bioreactor, and settling ponds. Infiltration controls to prevent water from entering mine workings have been utilized at two sites. At some sites, more than one project may have been completed during different years and a combination of techniques may have been used. Currently, there are no active treatment facilities.

## **Challenges in Doing Remediation**

Remediation is site specific and most of the sites in the Upper Animas Basin offer substantial challenges. Many sites lie on steep slopes at elevations 10,000 to 13,000 feet above sea level where it can snow any day of the year, and snow depths can reach 15 to 30 feet in winter. The construction season may last only three to four months. Avalanches are a constant hazard for at least half of the year and several sites lie directly in avalanche paths. Some sites have no vehicle access so that helicopters may be needed to transport equipment. Areas around the sites are fragile mountain tundra where heavy equipment can do substantial damage. Few sites have electric power needed for some types of treatment.

Hydrologic controls are the preferred method of remediation because they are frequently less expensive and need less maintenance than treatment. Drainage diversions around mine waste piles can be a good, inexpensive partial remediation method, yet it is difficult to totally isolate piles from water. Removal of mine waste piles can be a very effective remediation measure, but where does one put the material? In the Upper Animas Basin, some piles have been scooped up, consolidated, and then capped with clay or soil to reduce water infiltration. However, there are few large, flat areas in San Juan County that could be used as repositories for significant amounts of material. Trucking the wastes outside the region to a landfill would be prohibitively expensive. Another alternative, which was used for several sites, is to mill the mine wastes to remove the offending metals.

Many mine waste piles occur on steep slopes. As material was dumped from a portal, the piles themselves became conical with steep sides and small flat tops. Their shape makes them difficult to cap or amend with neutralizing agents.

Sub-surface hydrologic controls can be very effective, if the underground mine workings are accessible. Most mines in the Upper Animas Basin have not seen any activity in eighty to ninety years, and if entry is still possible, it is very dangerous. There may be no oxygen and the roof may collapse. Yet there are a few sites where sub-surface controls, including grouting or sealing areas above the mine from the surface may be possible, and they are being investigated.

Passive treatment must be tailored to a site and to the specific metals needing removal. Some treatment techniques can be ruled out for all but a handful of sites. Only a few sites have relatively large flat areas needed for treatment using settling ponds or wetlands, and these types of treatment lose their effectiveness when temperatures drop well below freezing during much of the year. Techniques such as anoxic drains need less space, but they need more maintenance to prevent them from clogging and are better suited for discharges with low iron and aluminum content. Metals such as zinc and manganese are more difficult to remove because pH must be raised to a high level to make them precipitate. Each site needs to be thoroughly characterized and evaluated to determine the feasibility of metal and acid removal.

## **Potential Remediation of Upper Cement Creek Sites**

The four large drainages in upper Cement Creek are by far the biggest anthropogenic sources of

metals in the upper Animas Basin. After collecting water quality and sediment samples over several years in Cement Creek, EPA stated that the area surrounding these drainages could qualify as a National Priority Site under CERCLA (Superfund). Currently, little support for listing exists in the local community, and an effort is underway for all parties to work cooperatively to better characterize the problem and identify the most appropriate method for reducing metal loading from this area. A number of remediation options are under consideration, including an active treatment plant.

Several studies are on-going in Cement Creek to characterize the current condition including additional water quality monitoring, a risk assessment by EPA and BLM, a water quality model of the creek by USGS for estimating the effect of metal load reductions at Gladstone on water quality downstream, and a mass loading analysis funded by Sunnyside Gold Corp. (Geochimica, 2012). Three studies have been completed regarding active treatment plant options. The first was done in 2007 by an EPA contractor (URS, 2007). The second was conducted by a contractor for Sunnyside Gold Corp. (MWH, 2012). Both studies indicate that while a treatment facility would cost several million dollars to construct, the really significant expense is operation which is estimated at just under \$1 million per year in perpetuity. ARSG is actively investigating new types of treatment technologies to reduce these operating costs. The third study was a legal analysis done by San Juan County on the advantages and disadvantages of using different legal frameworks for owning and operating a treatment plant. While these issues are an important part of the overall Watershed Plan, because of the expense of addressing these drainages and potential for active treatment, potential remediation of these sites is probably beyond the scope of the NPS program.

## **VI. MEASURING PROGRESS IN MEETING GOALS**

Recently, ARSG has completed a thorough analysis of data collected monthly over the past twenty years at the four gaging stations identified in Figure 3 above. The analysis has enabled the group to track changes in water quality in several locations in the basin. Some of these changes are substantial as shown in the graphical figures below.

### **Data Validation**

The water quality database consists of data collected from a number of different entities: U.S. Geological Survey, U.S. Environmental Protection Agency, U.S. Bureau of Reclamation, Colorado Division of Wildlife (River Watch program), Colorado Water Quality Control Division, Colorado Division of Reclamation, Mining, and Safety, Sunnyside Gold Corporation, and the Animas River Stakeholders Group itself. These entities tend to use their own reporting formats and use different labs for sample processing which in turn have their own reporting limits. All labs use EPA approved methods for processing.

ARSG has put all of the metal data that has been collected over the last 24 years in the Animas River Basin into one format so that all of the data can be analyzed. The data has been validated for the four gauging stations around Silverton, known as A72 (on the Animas River below Silverton), A68 (on the Animas River above the confluence with Cement Creek), M34 (near the mouth of Mineral Creek), and CC48 (near the mouth of Cement Creek). In the data validation process, ARSG has:

- ◆ corrected typos and eliminated data where it had been duplicated and entered into the database more than once,
- ◆ updated data in the analysis to consistent units (ug/l or mg/l),
- ◆ identified data that could be considered outliers,
- ◆ added lab reporting limits which were not initially supplied by the different entities,
- ◆ eliminated sample data that was missing

parameters that made it useable for analysis (*i.e.* samples that were missing dates collected).

Laboratories used by different entities use different reporting limits. Some labs use method of detection (MDL) as a limit. Others use reporting limits that are several times higher than the MDL to reduce the uncertainty in the accuracy of the reported value. For some labs, these higher reporting limits may be considered practical quantification limits (PQL's). Some agencies like EPA use the MDL as its reporting limit, but denote data between the MDL and PQL with a "U" or "J" to reflect some uncertainty in the accuracy of the value.

The reporting limits are important in analyzing copper, cadmium, and lead in the Animas Basin. These metals are toxic to aquatic life in very small, dissolved concentrations. Water quality standards to protect aquatic life are sometimes substantially below the reporting limit of some labs. This is especially true for older samples taken in the 1990's when reporting limits were frequently higher than they are today. For the other metals of concern in the Animas Basin - iron, aluminum, manganese, and zinc - reporting limits are not a major issue.

Typically, when the sample for a metal concentration is below the reporting limit, ARSG assigns a value equal to one-half the reporting limit for its analysis. If the reporting limit is high enough, one-half of its value can be higher than the standard. In those circumstances, ARSG generally did not use that reporting limit value (*e.g.* <3) in its analysis, because it may bias the results and could show a standard is being violated when there is no actual data substantiating a violation. All of the data that was not used in the analysis is still in the database.

In analyzing dissolved lead values at A72 from 2006-2011, we found fourteen River Watch samples were above that lab's reporting limit of 3 ug/l. All but one of these samples were collected during 2007-2009. During 2006-2011, none of the samples taken by Bureau of Reclamation, USGS, and WQCD were above 1 ug/l. (These agencies used a reporting limit of 1 ug/l or less.) Some of those samples were taken the same day as the River Watch samples. Also during that period, only two of the nineteen samples collected by EPA were over 1 but less than 3 ug/l. All of the rest were under 1 ug/l.

In almost all cases, the dates when anomalous dissolved lead samples were taken by River Watch at A72 correspond with high anomalous dissolved lead samples taken by River Watch at the other three Upper Animas River Basin gauges. These samples are all identified with light blue shading in the database for each gage.

In addition, there are a number of River Watch samples taken at Bakers Bridge and Trimble Lane that exhibit the same pattern. During the 2006-2011 period, a number of dissolved lead samples from 2007-09 were above 3 ug/l and the rest of the samples were below the reporting limit of 3 ug/l. The pH at these locations is generally around 8.0, so one wouldn't expect very much lead in the dissolved fraction. Over the past ten years, only River Watch has taken samples at these two sites.

After numerous conversations with River Watch, no one could determine why their samples during 2007-09 were higher than other agencies. ARSG did two analyses for lead at all four gages. One analysis includes the questionable River Watch data, and the other does not. After reviewing the analyses, we believe that the questionable data should not be used.

ARSG also identified a few outliers, specific metal samples that were approximately an order of magnitude higher than other samples from a particular location. Other metals in the same sample generally had values that were typical of that location. The individual outliers were not used in the analysis, but are still in the database with a notation. All data through 2011 is on the ARSG website.

- Stipuled entries: Value is an outlier of normal results indicating a probable error,
- **Yellow highlight**: Data evaluated and corrected or strikeout (invalidated and to be removed from use),

- **Strikeouts:** Data value determined to be invalid or redundant (entered more than once),
- **Blue highlight:** Questionable Pb values for Colorado River Watch (DOW) data.

## **Gage Station Analysis**

Through spreadsheet analysis, monthly metal concentrations and loads from three time periods for all metals of concern and pH were compared to existing standards at each of the four gages. The metals are aluminum (Al), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), and zinc (Zn). The time periods are 1991-mid 1996, 1998-2001, and 2007-2011. The first time period represent pre-remediation although there was some remediation during this timeframe by Sunnyside Gold. The first bulkhead in the American Tunnel was installed in July 1996. During the second time period, substantial remediation had taken place and Sunnyside Gold was running upper Cement Creek through its treatment plant most of the time as part of the stipulations under the consent decree. The large increases in adit discharges in upper Cement Creek had not yet occurred. The year 2002 was excluded from this period because runoff was a record low that year which would have skewed the analysis. The third time period represents the most recent five-year period for which there was data. No active treatment plants were operating at mine sites, and the large adit discharges in upper Cement Creek appeared to have stabilized. For a few metals, not enough data exists in the earlier time periods to analyze.

## ***Water Quality Standards***

Water quality standards in the upper Animas Basin were set in 2001. A number of standards to protect aquatic life are site specific because Table Value Standards (TVS) typically used by WQCC are thought to be unattainable. Some of the graphs below show both the current standard and TVS for specific metals simply to demonstrate that there is a difference between the two. In several graphs, the standard is TVS except for a couple of months in the year where TVS is unattainable. Standards for aluminum and iron are measured by using the 50<sup>th</sup> percentile of the total recoverable metal available (Trec). Standards for the other metals are measured by using the 85<sup>th</sup> percentile of the dissolved fraction (Dis).

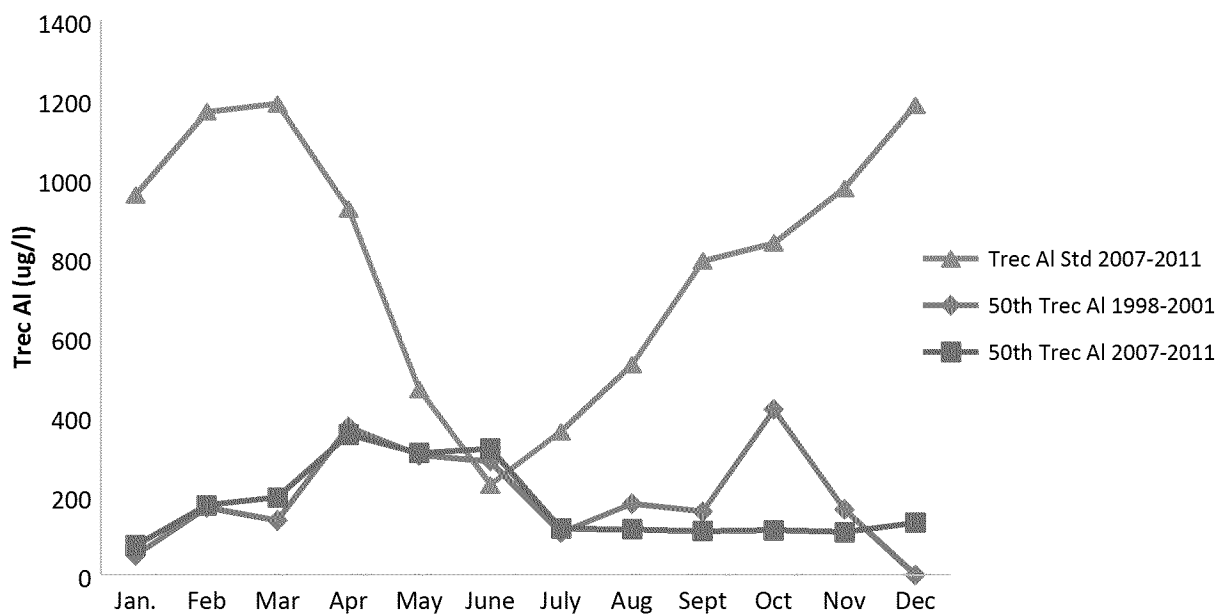
Several stream segments, such as Cement Creek, in the upper Animas Basin don't have an aquatic life use classification and numeric standards are ambient or existing condition. Thus, the graphs depicting water quality at the Cement Creek gage don't have standards.

In 2001, it appeared that a number of stream segments were meeting or could meet the cadmium TVS. Since that time, the cadmium TVS has become much stricter and in several locations this newer TVS may not be attainable. The old cadmium TVS is depicted on several graphs to show what the goal was when the standards were adopted.

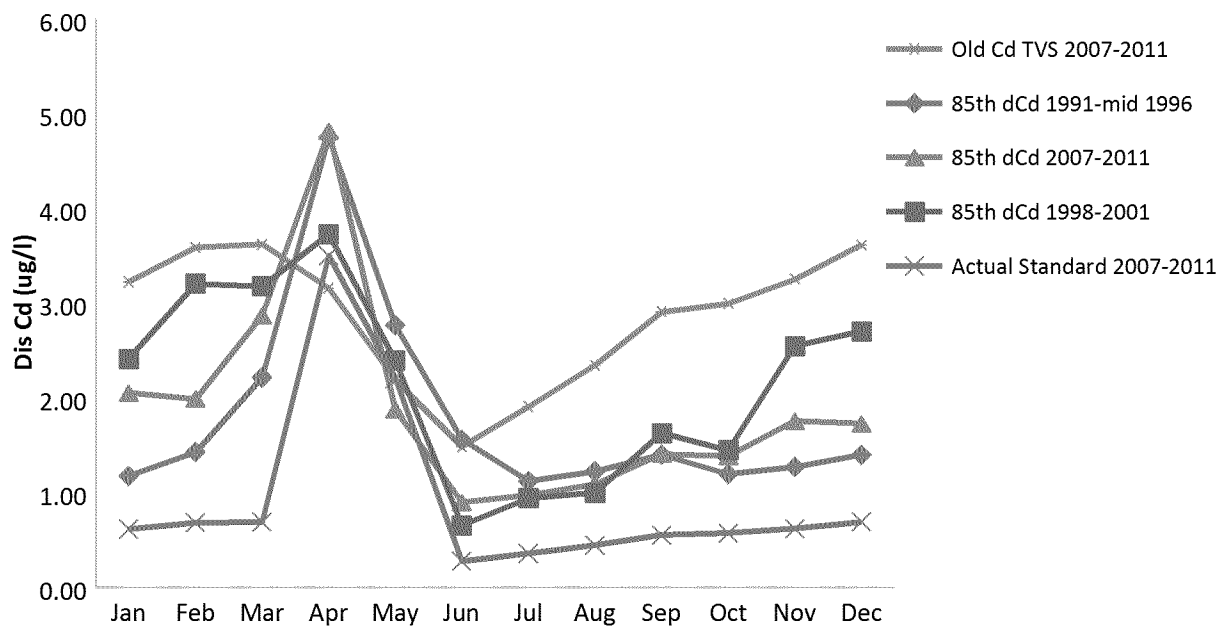
The figures below show the increases and decreases in metal concentrations for different metals at different gages. Each set of figures is followed by a short discussion. A broader discussion of water quality in the basin follows all the figures. Metal loads were also calculated, and figures depicting the changes in loads are in Appendix C.

**Figure 4 – Metal Concentrations in the Animas River above the Confluence with Cement Creek (A68)**

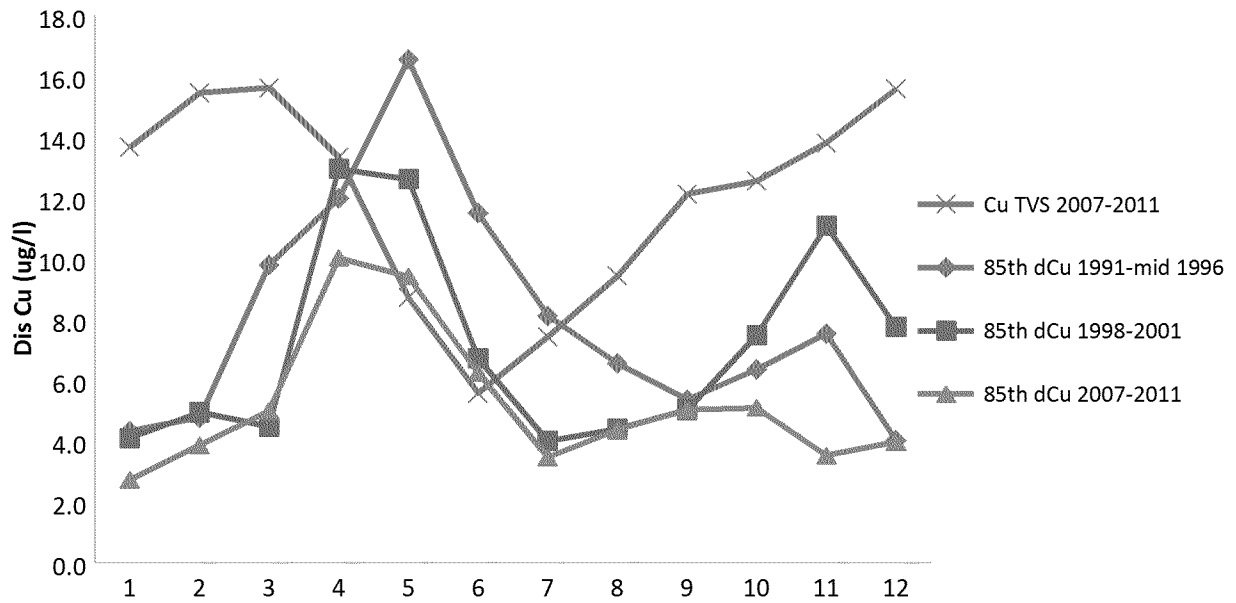
## Trec Al Conc. At A68



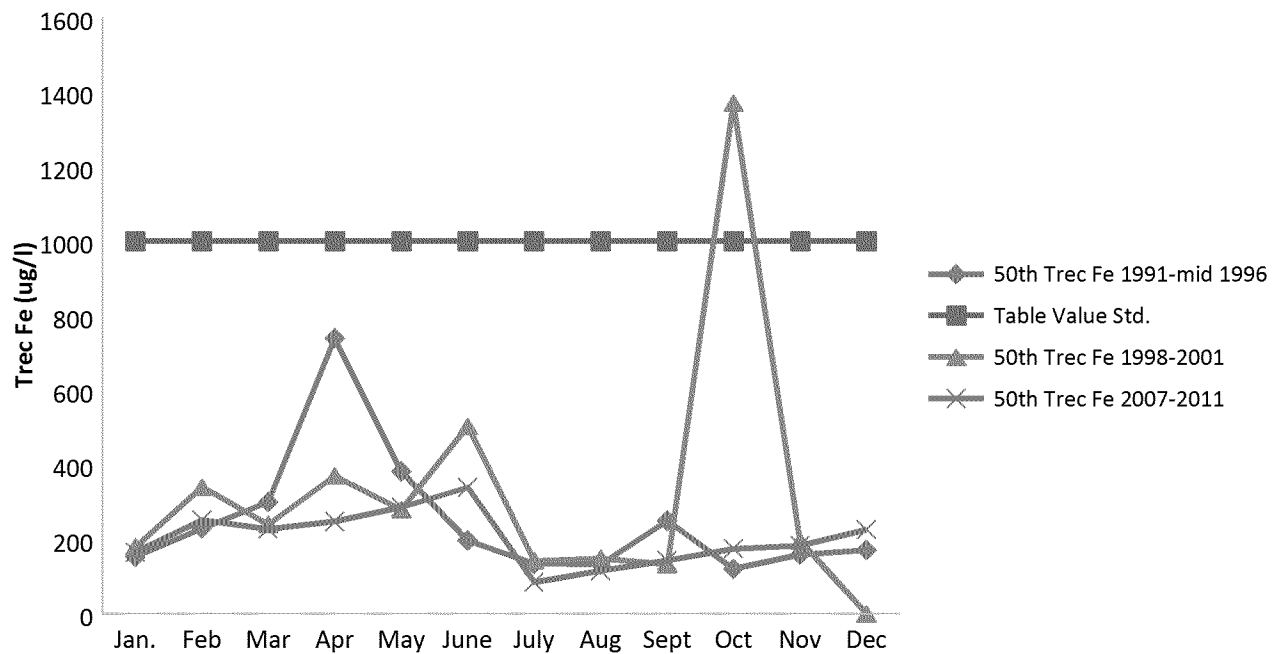
## Dis Cd Conc. At A68

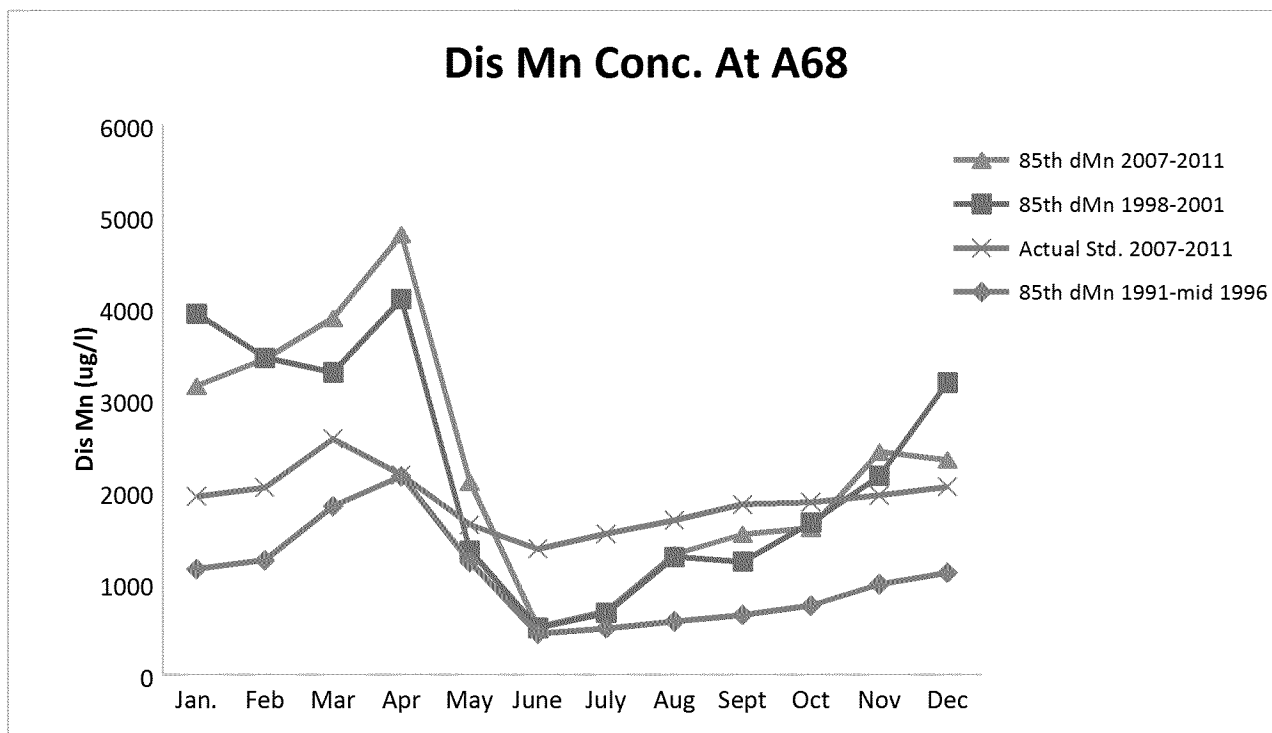
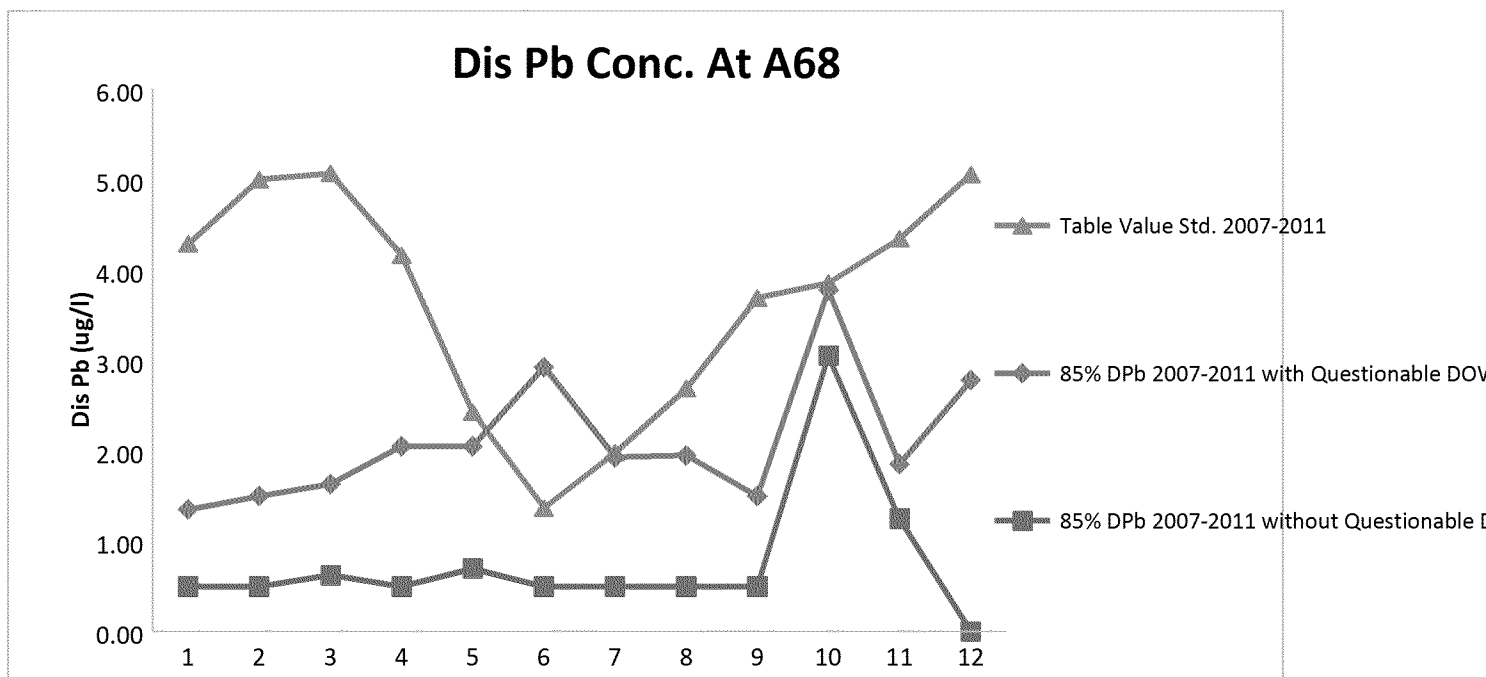


### Dis Cu Conc. At A68



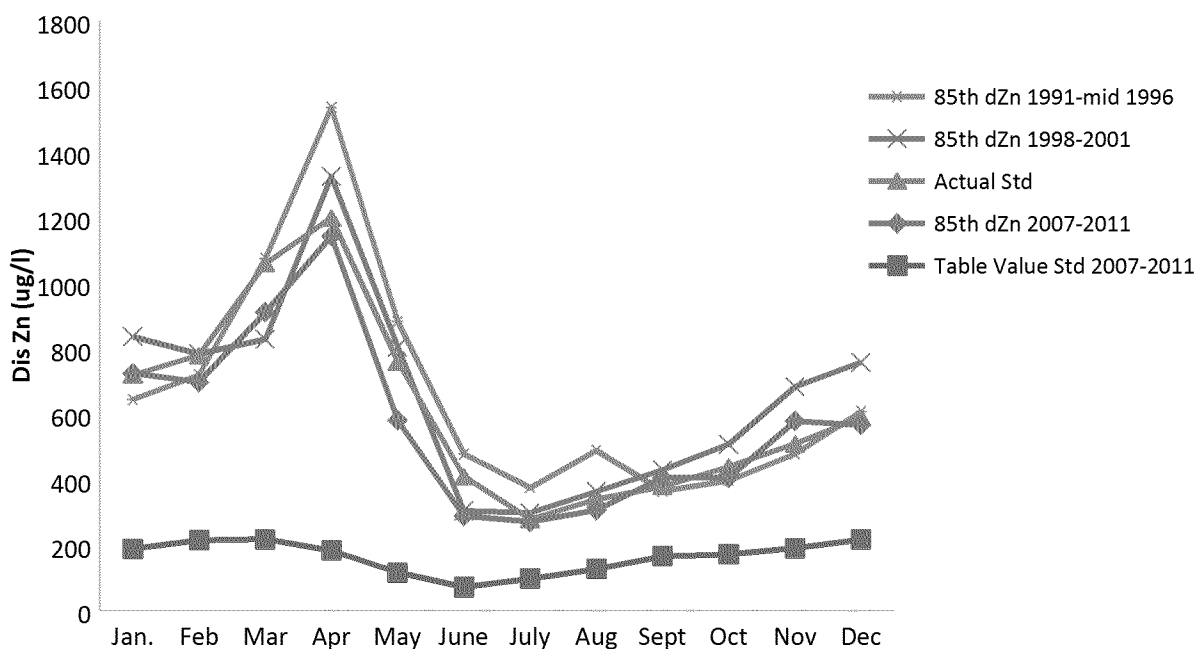
### Trec Fe Conc. at A68



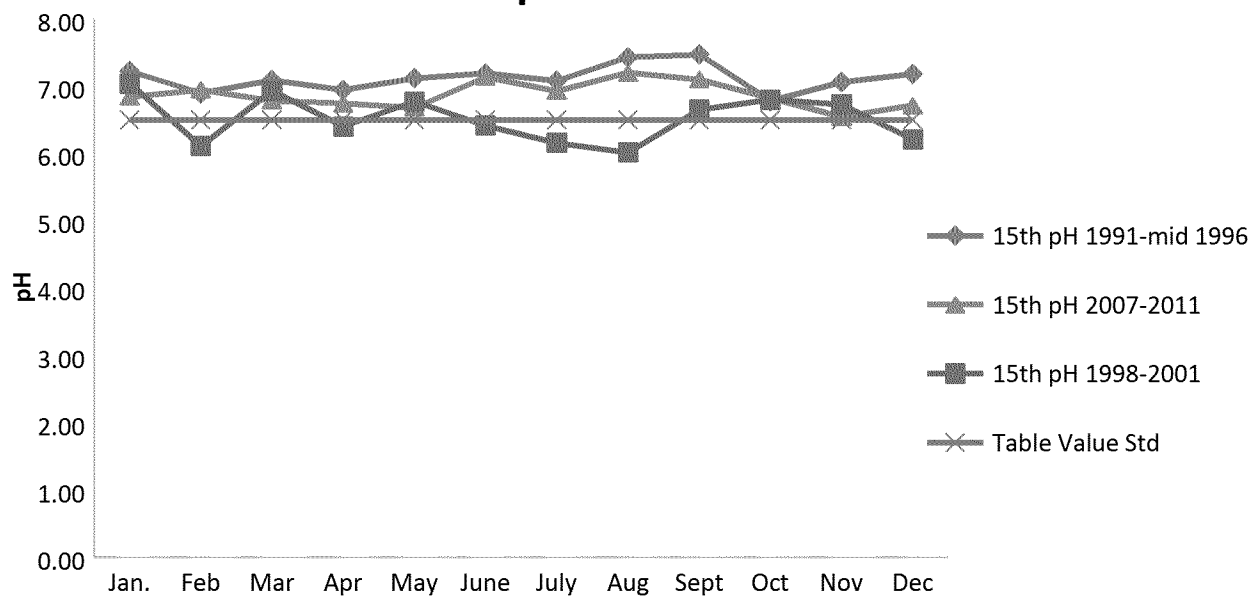




## Dis Zn Conc. at A68



## pH at A68

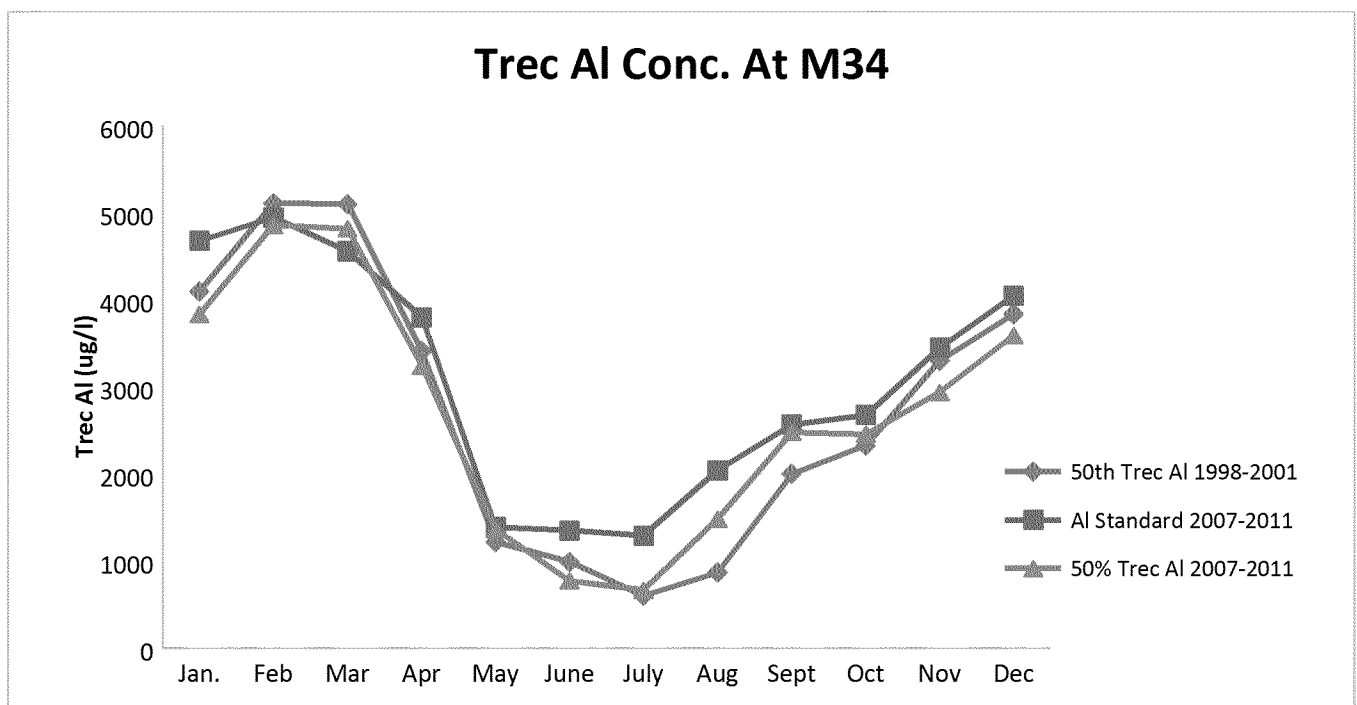


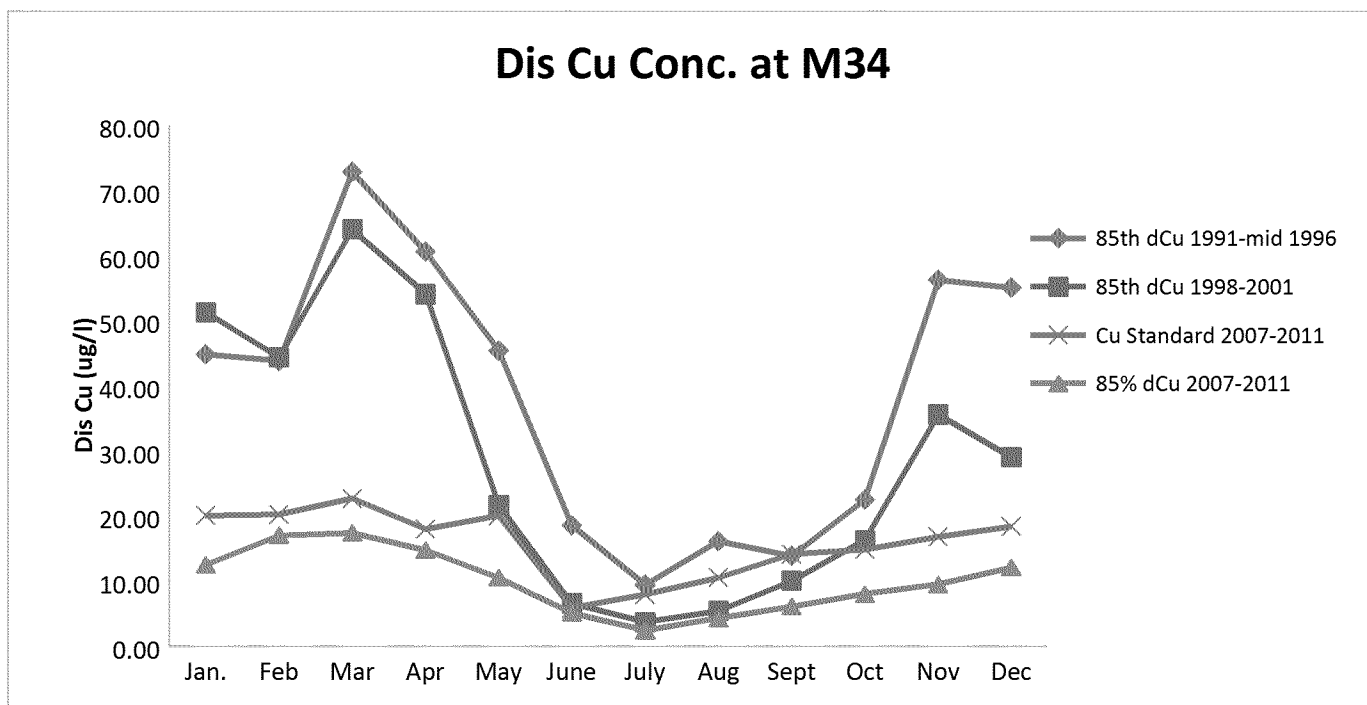
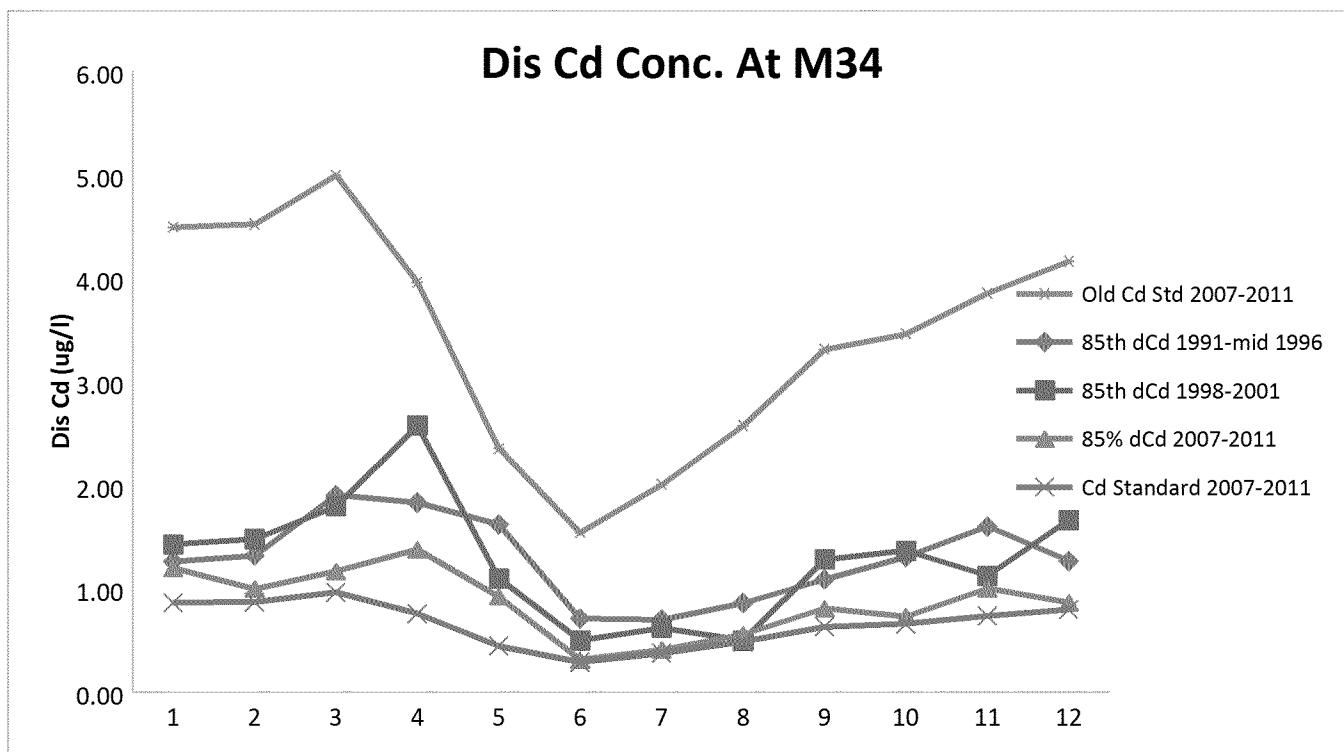
## Animas River above Silverton, A68

Estimated reductions in metal concentrations in the UAA for A68 are generally not that great, because there are not readily identifiable large sources of metals. A substantial amount of Cd, Mn, and Zn enters the Animas River from unidentified, diffuse sources between Howardsville and A68, and there is minimal remediation potential higher upstream. Most of the sites that can be readily remediated have been completed including the Sunnyside Gold Corp. tailings ponds

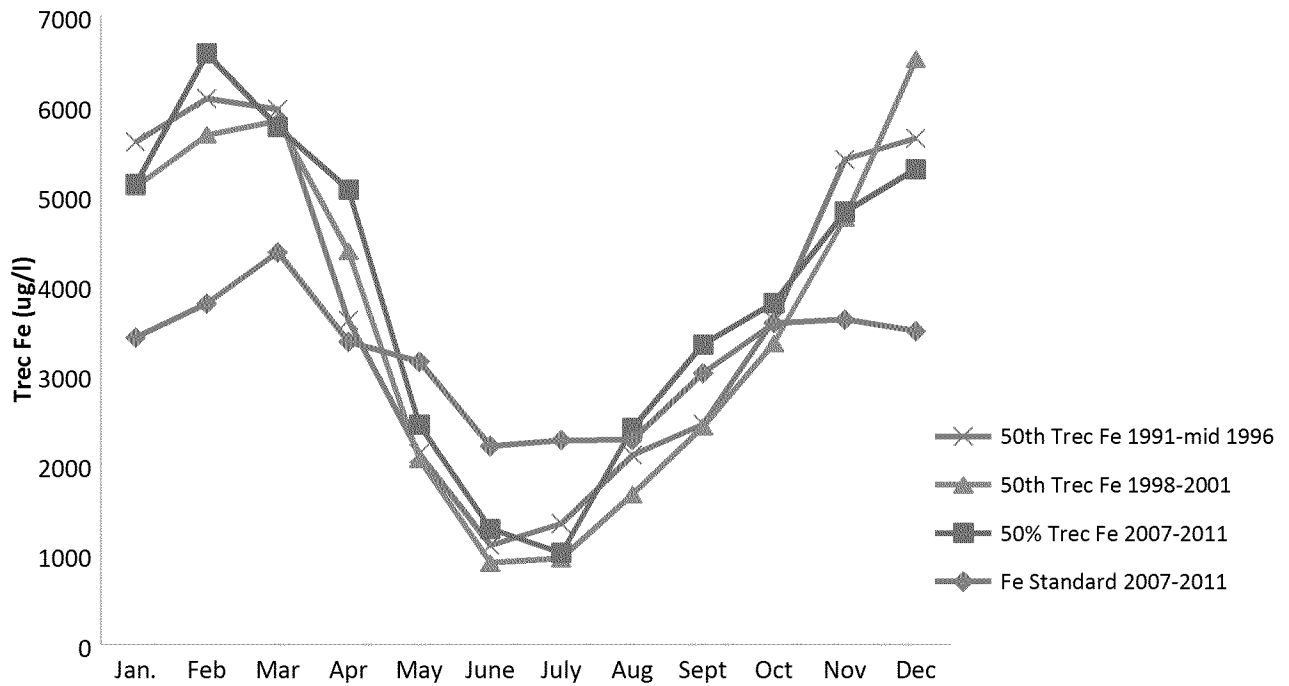
Overall, copper concentrations and peak zinc concentrations have seen substantial reductions. The most problematic metals currently are cadmium and manganese. Cadmium concentrations have remained high relative to the current standard despite remediation. Manganese concentrations have substantially increased for unknown reasons.

**Figure 5 – Metal Concentrations in Mineral Creek (M34)**

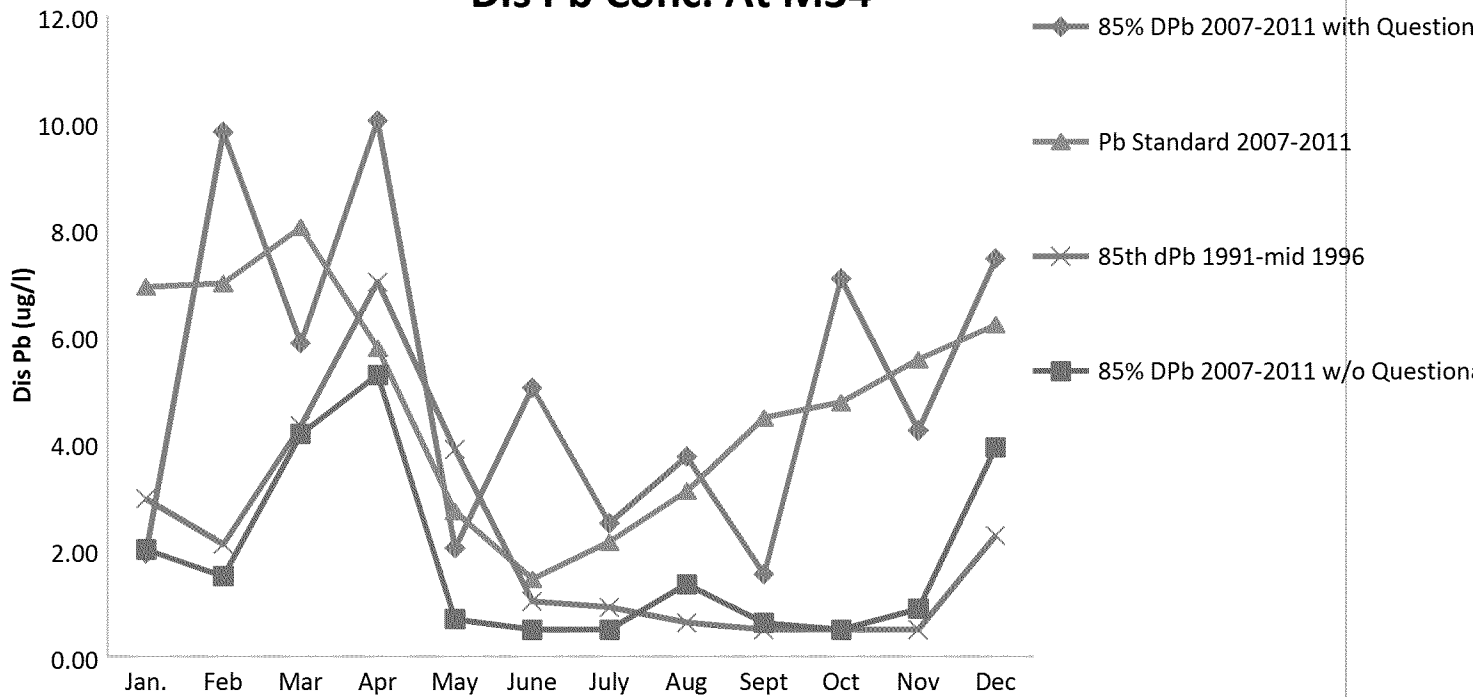




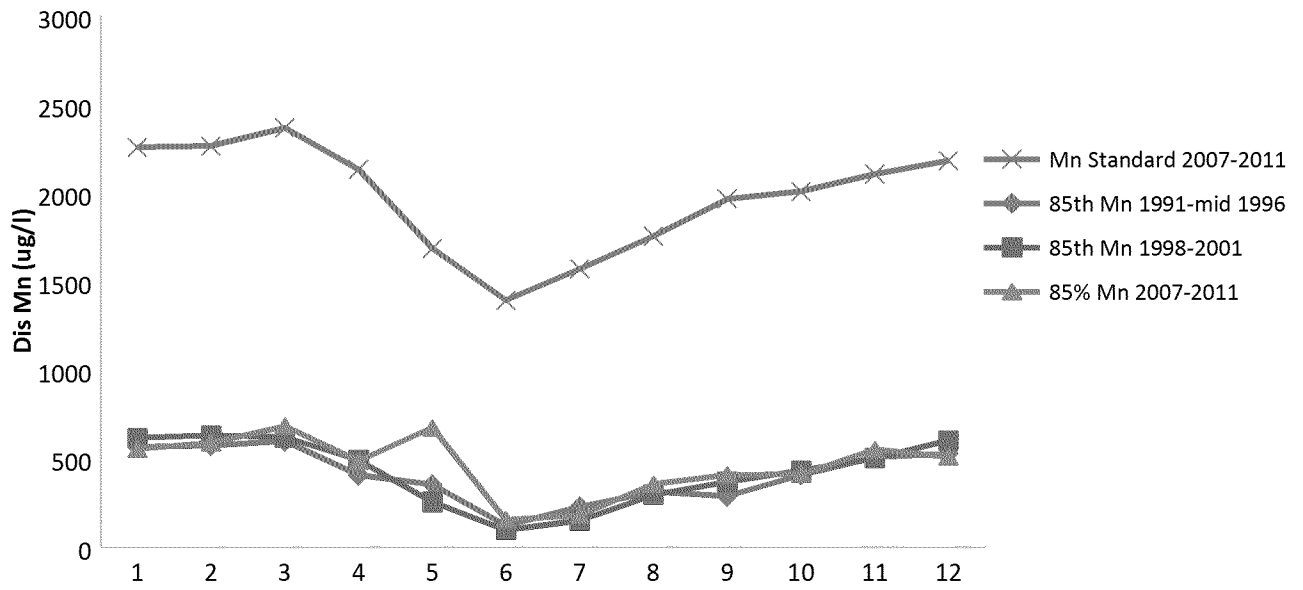
### Trec Fe Conc. At M34



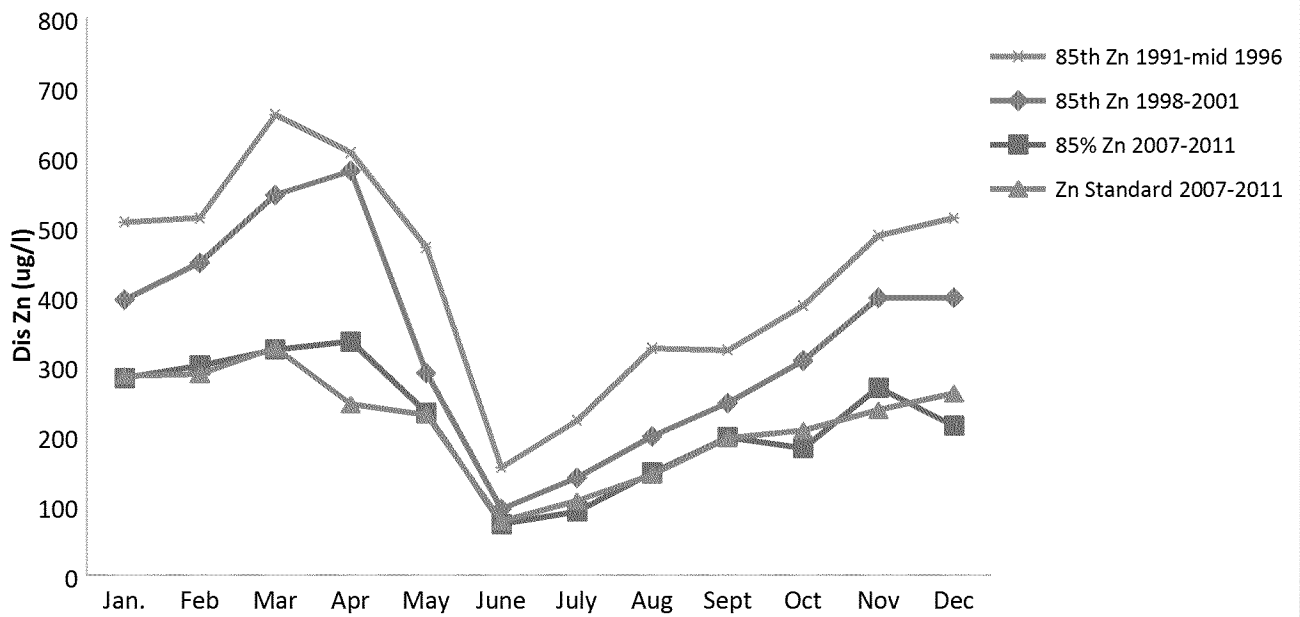
### Dis Pb Conc. At M34

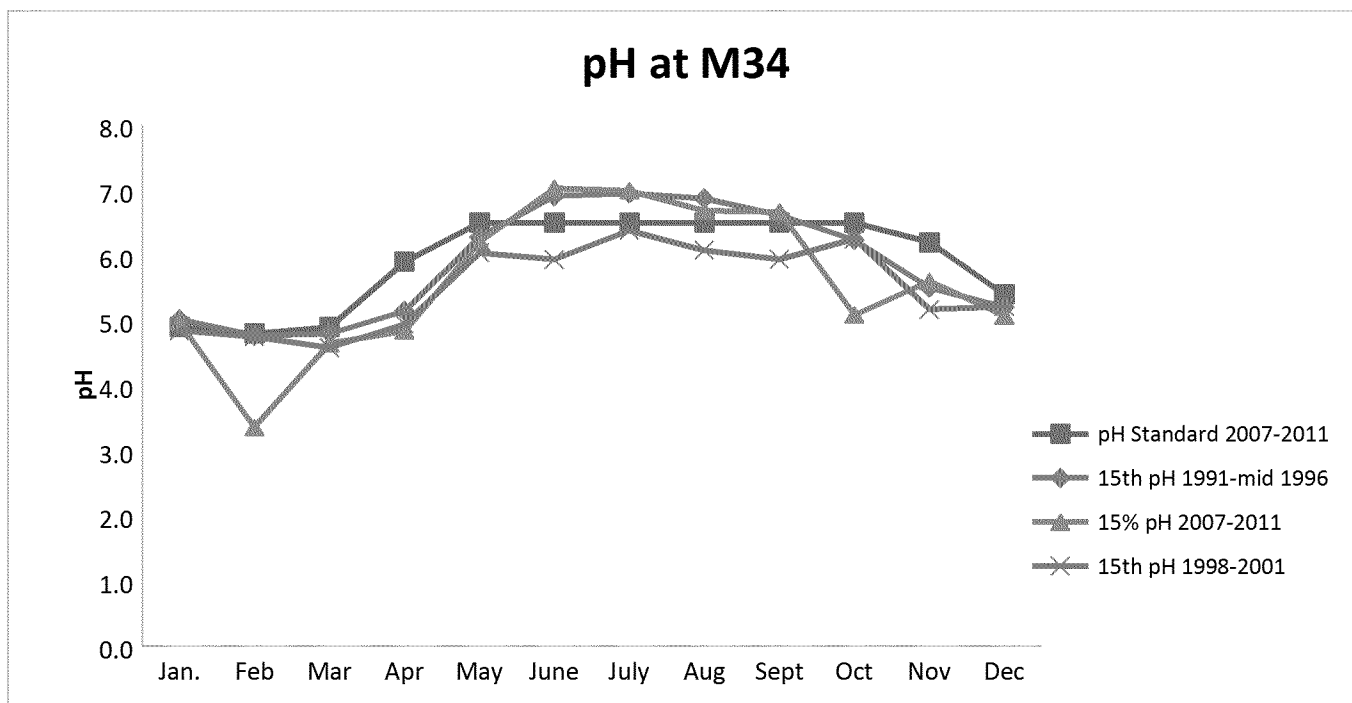


### Dis Mn Conc. At M34



### Dis. Zn Conc. at M34





### ***Mineral Creek near Silverton, M34***

Significant remediation has been completed in Mineral Creek with significant results. Copper concentrations at M34 have dropped approximately 50% - 80% depending on time of year. Zinc concentrations have fallen by approximately 40% - 50%. Cadmium has dropped approximately 25%. Not surprisingly, aluminum and iron concentrations have not changed given that sources of the metals are predominately natural and not associated with the remediated sites.

From data for 2007 - 2011, copper is now meeting water quality standards; zinc is virtually meeting standards, and cadmium is fairly close to meeting standards. This data does not show the impact of the Koehler grouting project, the Silver Ledge remediation, or the future Bullion King remediation. As we collect and analyze more recent data, these three metals should all meet standards.

Unfortunately, we expect to see little aquatic improvements in the mainstem of Mineral Creek with these metal reductions because pH is too low in winter and spring, and iron and aluminum concentrations, from predominately natural sources, are too high to support most aquatic life. Note that concentrations of zinc, copper and cadmium have all declined with remediation, whereas there have been no changes in iron and aluminum concentrations. However, we do expect to see improvements in aquatic life downstream of the confluence of Mineral Creek and the Animas River, if loading in Cement Creek can be reduced.